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CERTAIN INCONSISTENCIES IN THE MATHEMATICAL THEORY OF A NEW RELATIVITY OF DR. SIR SHAH SULAIMAN

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Communicated by Rai Sahib Dr. P. L. Srivastava
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SUMMARY

This note contains a discussion of the methods by which a Planet's path has been obtained. The later methods of the New Theory of Relativity have been shown to depend on approximations, unjustifiable and inconsistent with the theory, while in the first method which has been unreasonably discarded by the Hon'ble Sir Shah Muhammad Sulaiman, the equations have been deduced correct up to the 2nd order terms and solved to give $\triangle\omega = \frac{3\pi\mu^2}{D^2h^2}$ which is inconsistent with observations. Michelson-Morley Experiments and the subject of Relative Velocity have been briefly touched on and the explanations in the New Theory shown to be inconsistent with observations. It has also been shown that the later works have no definite connection with the fundamental theory, while the results of the earlier works are contrary to observations.

In this paper I have tried to point out certain inconsistencies in the Theory of a New Relativity by Dr. Sir Shah Sulaiman up to what has been published as yet. I may also say that Mr. S. C. Damle has also pointed out some inaccuracies in his paper " A note on the Theory of a New Relativity " published in the Proceedings of the Academy of Sciences, India, Vol. VI, Part I, 1936 But, I think, the inconsistencies pointed out by me have not yet appeared in any paper.

I

§1. *Deduction of Polar Differential Equation of Planet's Path* in the Mathematical Theory of New Relativity, by Dr. Sir Shah Sulaiman published in the Proceedings of the Academy of Sciences, India.

So far, up to Chapter XVI only four methods of finding the Polar Differential Equation of the path of a planet have been shown. These are :

1. The method of taking all corrections (*viz*, of aberration, Doppler's Principle due to displacement and motion, and finiteness of the velocity of gravitation) to Newtonian formulæ of motion.
(Chapter I, Chapter VIII)

2. Method of using undetermined coefficients in the equation of the path of a particle affected by gravitation. (Chapter XIII)
3. Method of using undetermined coefficients in the equation of energy. (Chapter XVI, §4)
4. Method of using the formulæ of Lienard and Wiechart for retarded electric potential in the expression for retarded gravitational potential. (Chapter XVI)

It has been shown, in what follows, that not one of the above four methods is conclusive. In fact, in method (1) the equations have been solved, and only the expression for the advance of perihelion has been found out and confirmed by the use of the formulæ for disturbed elliptic motion, and it is found that it does not tally with observed facts.

Method (4) is decidedly incorrect owing to unproved assumptions Methods (2) and (3) labour under the same mistakes as shall be shown herein. These are discussed in §§ 2, 3, 4, 5 following.

§2. (*a*) The following are the only corrections applied to the Newtonian formulæ, and there are no others :

(*i*) Change in the effect of gravitation due to displacement and motion.

(*ii*) Finiteness of the velocity of Gravitation.

(*iii*) Effect of Aberration.

(*iv*) Effect of Doppler's Principle.

The ratio used in (*i*) is $1:(1-\text{v}/\text{D})^3$.

The angle of aberration instead of being taken $\sin^{-1}\left(\frac{r\dot{\theta}}{\text{D}}\right)$ has been taken as in § VI, Chap. VIII from

$$\frac{\sin\alpha}{ds/dt}=\frac{\sin(\phi-\alpha)}{\text{D}}=\frac{\sin(\pi-\phi)}{\sqrt{\text{D}^2+2\text{D}\cos\phi\frac{ds}{dt}+\left(\frac{ds}{dt}\right)^2}}$$

where $\tan\phi=-\frac{rd\theta}{dr}\left(\frac{\pi}{2}<\phi<\pi\right)$

i.e., $\sin\alpha=\frac{1}{\text{D}}\;r\frac{d\theta}{dt}+\frac{1}{\text{D}^2}\;r\frac{d\theta}{dt}\;\frac{dr}{dt}+\text{O}(\text{D}^{-3})$

so that $\cos\alpha=1-\frac{1}{2}\frac{r^2}{\text{D}^2}\left(\frac{d\theta}{dt}\right)^2+\text{O}(\text{D}^{-3})$*.

[* The formula (36·2) that

$$\cos\alpha=1-\tfrac{1}{2}\frac{r^2}{\text{D}^2}\left(\frac{d\theta}{dt}\right)^2-\frac{1}{\text{D}^2}\left(\frac{dr}{dt}\right)^2+\text{O}(\text{D}^{-3})\text{ is wrong.}$$
]

The velocity of recession of planet and the sun is

$$\frac{dr}{dt} - \frac{1}{D}\left(\frac{rd\theta}{dt}\right)^2 + O(D^{-2})$$

With these corrections the equations of motion become

$$\ddot{r} - r\dot{\theta}^2 = -\frac{\mu}{r^2} + \frac{3\mu}{D}\frac{1}{r^2}\frac{dr}{dt} - \frac{5}{2}\frac{\mu}{D^2}\left(\frac{d\theta}{dt}\right)^2 - \frac{3\mu}{D^2}\frac{1}{r^2}\left(\frac{dr}{dt}\right)^2 + O(D^{-3}) \quad \ldots \quad (1)$$

$$\frac{1}{r}\frac{d}{dt}(r^2\dot{\theta}) = \frac{1}{r}\frac{\mu}{D}\frac{d\theta}{dt} - \frac{2\mu}{D^2}\frac{1}{r}\frac{d\theta}{dt}\frac{dr}{dt} + O(D^{-3}) \quad \ldots \quad (2).$$

Integration of Equations of Motion.—We get from the expression for $\frac{1}{r}\frac{d}{dt}(r^2\dot{\theta})$ that

$$r^2\frac{d\theta}{dt} = h\left\{1 + \frac{\mu\theta}{Dh} - \frac{2\mu}{D^2h}\int\frac{d\theta}{dt}dr\right\} + O(D^{-3})$$

Now, as usual, we write:

$$r = \frac{1}{u},\quad \frac{dr}{dt} = -\frac{1}{u^2}\frac{du}{d\theta}\dot{\theta} = -h\frac{du}{d\theta}\left\{1 + \frac{\mu\theta}{Dh} - \frac{2\mu}{D^2h}\int\frac{d\theta}{dt}dr + O(D^{-3})\right\}$$

$$\frac{d^2r}{dt^2} = -\frac{1}{u^2},\ \frac{d^2u}{d\theta^2}.\dot{\theta}^2 - h\frac{du}{d\theta}\dot{\theta}\left\{\frac{\mu}{Dh} - \frac{2\mu}{D^2h}\frac{d}{d\theta}\int\frac{d\theta}{dt}dr + O(D^{-3})\right\}$$

Substituting these values of $r, \dot{r}, \ddot{r}$ in Equation (1), we get:

$$-\frac{1}{u^2}\dot{\theta}^2 u_{\theta\theta} - hu_\theta\left[\frac{\mu}{Dh} - \frac{2\mu}{D^2h}\frac{d}{d\theta}\int\dot{\theta}dr + O(D^{-3})\right]\dot{\theta} - \frac{1}{u}\dot{\theta}^2$$

$$= -\mu u^2 + \frac{3\mu}{D}\frac{1}{r^2}\left(-\frac{1}{u^2}u_\theta\dot{\theta}\right) - \frac{5}{2}\frac{\mu}{D^2}\dot{\theta}^2 - \frac{3\mu}{D^2}\frac{1}{r^2}\left(\frac{1}{u}.u_\theta{}^2\dot{\theta}^2\right) + O(D^{-3})$$

Dividing the above by $-\frac{1}{u^2}\dot{\theta}^2$, we get:

$$u_{\theta\theta} + \frac{hu^2u_\theta}{\dot{\theta}}\left[\frac{\mu}{Dh} - \frac{2\mu}{D^2h}\frac{d}{d\theta}\int\frac{d\theta}{dt}dr\right] + u = \frac{\mu u^4}{\dot{\theta}^2} + \frac{3\mu u^2}{D\dot{\theta}}u_\theta + \frac{5}{2}\frac{\mu}{D^2}u^2 + \frac{3\mu}{D^2}u^2{}_\theta + O(D^{-3})$$

$$i.e., \frac{d^2u}{d\theta^2} - \frac{2\mu}{Dh}\frac{hu^2}{\dot{\theta}}u_\theta - \frac{3\mu}{D^2}u_\theta{}^2\left[1 + \frac{2}{3}\frac{u^2}{\dot{\theta}u_\theta}\frac{d}{d\theta}\int\dot{\theta}dr\right] - \frac{5}{2}\frac{\mu}{D^2}u^2 + u = \frac{\mu u^4}{\dot{\theta}^2} + O(D^{-3})$$

Here, putting $\dot{\theta}=hu^2\left\{1+\frac{\mu}{Dh}\theta-\frac{3\mu}{D^2h}\int\dot{\theta}dr\right\}+O(D^{-3})$ we get in the 3rd term:

$$\frac{d}{d\theta}\int\dot{\theta}dr=\frac{d}{d\theta}\int hu^2dr+O(D^{-1})=-\frac{d}{d\theta}(hu)+O(D^{-1})=-hu_\theta+O(D^{-1})$$

so that the 3rd term

$$=-\frac{3\mu}{D^2}u^2{}_\theta\left[1-\frac{2}{3}\frac{hu^2}{hu^2[1+O(D^{-1})]}+O(D^{-1})\right]=-\frac{\mu}{D^{-2}}u_\theta{}^2+O(D^{-3})$$

Hence, we get:

$$\frac{d^2u}{d\theta^2}-\frac{2u}{Dh}\frac{du}{d\theta}\frac{1}{1+\frac{\mu\theta}{Dh}+O(D^{-2})}-\frac{\mu}{D^2}u_\theta{}^2-\frac{5}{2}\frac{\mu}{D^2}u^2+u$$

$$=\frac{\mu/h^2}{\left\{1+\frac{\mu}{Dh}\theta+\frac{2\mu}{D^2}u+O(D^{-3})\right)}+O(D^{-3})$$

Now, expanding in powers of (D^{-1}), and putting $\frac{\mu}{Dh}=k$ the right-hand side is

$$\frac{\mu}{h^2}\left(1-2k\theta+3k^2\theta^2-\frac{4\mu}{D^2}u\right)+O(D^{-3})$$

$$=-4k^2u+\frac{\mu}{h^2}(1-2k\theta+3k^2\theta^2)+O(D^{-3})$$

Transposing this first term to the left side, we get:

$$\frac{d^2u}{d\theta^2}-2k(1-k\theta)\frac{du}{d\theta}-\frac{\mu}{D^2}\left(\frac{du}{d\theta}\right)^2-\frac{5}{2}\frac{\mu}{D^2}u^2+u(1+4k^2)$$

$$=\frac{\mu}{h^2}(1-2k\theta+3k^2\theta^2)+O(D^{-3})$$

This is the correct polar differential equation of the path of the planet.

§ 2. (*b*) *Solution of the equation* for the determination of Advance of Perihelion, we suppose:

$$\frac{h^2u}{\mu}=1+\alpha k+\beta k^2+rk\theta+\delta k^2\theta^2+e(1+\lambda k\theta+2^2k^2\theta^2)\cos(\theta-\omega+\Omega k^2\theta)+O(D^{-3})$$

where α, β, r, δ, λ, v etc. are numerical constants,

i.e, we write:

$$\frac{h^2}{\mu}u=1+\alpha k+\beta k^2+rk\theta+\delta k^2\theta^2+e(1+\lambda k\theta+rk^2\theta^2)\cos(\theta-\omega)-\Omega k^2\theta e\sin(\theta-\omega)+O(D^{-3})$$

$$+4k^2\frac{h^2}{\mu}u=\quad+4k^2\quad+e(4k^2+\quad)\cos(\theta-\omega)\quad+O(D^{-3})$$

$$-\frac{5}{2}\frac{\mu}{D^2}u^2\frac{h^2}{\mu}=\quad-\frac{5}{2}k^2\quad+e(-5k^2+\quad)\cos(\theta-\omega)\quad+O(e^2D^{-2})+O(D^{-3})$$

$$-\frac{\mu}{D^2}\quad\frac{h^2}{\mu}\left(\frac{du}{d\theta}\right)^2 = \qquad\qquad\qquad\qquad +O(D^{-3})$$

$$-2k\frac{du}{d\theta}\quad\frac{h^2}{\mu} = \qquad -2\gamma k^2 \quad +e(-2\lambda k^2+ \qquad)\cos(\theta-\omega)-(-2\lambda k^2\theta-2k)e\sin(\theta-\omega)$$

$$+O(D^{-3})$$

$$+2k^2\theta\frac{du}{d\theta}\quad\frac{h^2}{\mu} = \qquad\qquad\qquad\qquad -(2k^2\theta \qquad)e\sin(\theta-\omega)$$

$$+O(D^{-3})$$

$$\frac{h^2}{\mu}\quad\frac{d^2u}{d\theta^2} = \quad +2\delta k^2 \quad +e(-1-\lambda k\theta-\nu k^2\theta^2 \qquad\qquad -(2\lambda k+4\nu k^2\theta$$

$$+2\nu k^2-2\Omega k^2)\cos(\theta-\omega) \qquad -\Omega k^2\theta)e\sin(\theta-\omega) \quad +O(D^{-3})$$

Hence, the value of the left hand side of the Differential Equation multiplied by $\frac{h^2}{\mu}$ comes out to be

$$\begin{aligned}
=&\{1+\alpha k+k^2(\beta+\tfrac{3}{2}-2\gamma+2\delta)+\gamma k\theta+\delta k^2\theta^2\}\\
&+e\cos(\theta-\omega)\{(2\nu-2\Omega-2\lambda-1)k^2\}\\
&-e\sin(\theta-\omega)\{(2\lambda-2)k+(4\nu-2\lambda+2)k^2\theta\}\\
&+O(D^{-3})+O(e^2D^{-2})
\end{aligned}$$

But this must identically be equal to

$$1-2k\theta+3k^2\theta^2+O(D^{-3})$$

Therefore, we must have

$$\alpha=0,\ \beta+\tfrac{3}{2}-2\gamma+2\delta=0,\ \gamma=-2,\ \delta=3$$

Whence α, β, γ, δ are ascertained and

$$\begin{aligned}
2\nu-2\Omega-2\lambda-1&=0\\
2\lambda-2&=0\\
4\nu-2\lambda+2&=0
\end{aligned}$$

whence λ and μ are found and

$$\Omega=-\tfrac{3}{2}.$$

Hence, the solution of the Diff. Eq. is

$$\mu=\frac{\mu}{h^2}\{1-\tfrac{23}{2}k^2-2k\theta+3k^2\theta^2+e(1+k\theta)\cos(\theta-\overline{\omega+\tfrac{3}{2}k^2\theta})+O(D^{-3})\}$$

Thus, the formula for the advance of Perihelion in one revolution is

$$\varepsilon=\left[\frac{3}{2}k^2\theta\right]_0^{2\pi}=3\pi k^2=\frac{3\pi\mu^2}{D^2h^2}$$

instead of $\frac{6\pi\mu^2}{D^2h^2}$

§2. (c) The above expression for the advance of Perihelion is verified by the use of the formulæ for Disturbed Elliptic Motion together with the solution of two other Diff. Eqs. We have:

if Disturbing Force is	Advance is
$f_1 = +\frac{3\mu}{D}\frac{1}{r^2}\frac{dr}{dt}$	$\Delta\omega_1 = \text{Zero} + O(D^{-2})$
$f_2 = -\frac{5\mu}{2D^2}\left(\frac{d\theta}{dt}\right)^2$	$\Delta\omega_2 = \frac{5\pi\mu^2}{D^2 h^2} + O(D^{-3})$
$f_3 = -\frac{3\mu}{D^2}\frac{1}{r}\left(\frac{dr}{dt}\right)^2$	$\Delta\omega_3 = \text{Zero} + O(D^{-3})$
$f_4 = +\frac{\mu}{D}\frac{1}{r}\frac{d\theta}{dt}$	$\Delta\omega_4 = \text{Zero} + O(D^{-2})$
$f_5 = -\frac{2\mu}{D^2}\frac{1}{r}\frac{d\theta}{dt}\frac{dr}{dt}$	$\Delta\omega_5 = -\frac{4\pi\mu^2}{D^2 h^2} + (O(D^{-3})$

Thus, we have to calculate the effects of f_1 and f_4 by the method of approximate solution. Now, to calculate the effects of (1) f_1 or (2) f_4 or (3) f_1 and f_4 combined, we get in all these three cases, equations of the form:

$$\frac{d^2u}{d\theta^2} - (nk - \chi k^2\theta)\frac{du}{d\theta} + u = \frac{\mu}{h^2}(1 - 2\eta k\theta + 3\eta k^2\theta^2)$$

where the numerical constants n, χ, η are

$$\left.\begin{array}{ll} \text{for } f_1 & n = 3,\ \chi = 0,\ \eta = 0 \\ \text{for } f_4 & n = -1,\ \chi = -1,\ \eta = 1 \\ \text{for } f_1 + f_4 & n = 2,\ \chi = 2,\ \eta = 1 \end{array}\right\}$$

Assuming a solution of the form

$$u = \frac{\mu}{h^2}\{1 + \alpha k + \beta k^2 + \gamma k\theta + \delta k^2\theta^2 + e(1 + \lambda k\theta + \nu k^2\theta^2)\cos(\theta - \omega + \Omega k^2\theta) + O(D^{-3})\}$$

we get the following equations for determining Ω

$$2\nu - 2\Omega - n\lambda = 0$$
$$2\lambda - n = 0$$
$$4\nu - n\lambda + \chi = 0$$

so that $\Omega = -\frac{n^2 + 2x}{8}$

$\therefore$ For f_1 $\Omega = -\frac{9}{8}$ for f_4 $\Omega = +\frac{1}{8}$ for $f_1 + f_4$ $\Omega = -1$

Thus, in any way, the advance of perihelion for $f_1 + f_4$

$$= \Delta\omega_1 + \Delta\omega_4 = -\tfrac{1}{4}\frac{\pi\mu^2}{D^2h^2} + \tfrac{9}{4}\frac{\pi\mu^2}{D^2h^2} = \frac{2\pi\mu^2}{D^2h^2}$$

Thus, the value of the total Advance of Perihelion is

$$\left(\tfrac{9}{4}+5+0-\tfrac{1}{4}-4\right)\ \frac{\pi\mu^2}{D^2h^2}=\frac{3\pi\mu^2}{D^2h^2}$$

This confirms the previous result.

§2. (*d*) On page 166, Vol. V, Pr. Ac Sc., India, it is remarked that "With appropriate values (the terms in the theory of resisting medium), the effect of the extra terms in the attractive forces which cause perturbations in the major axis, the eccentricity and even the longitude of the perihelion can be substantially reduced and even made to vanish."

In order to meet D. R. Hamilton's criticism regarding the effects on the eccentricity, if K of Eq. (38. 1) is put$=\dfrac{3\mu}{2D}$ obviously the Advance of Perihelion is further lowered which is farther from truth. If, on the other hand, the coefficients are so arranged as to raise the value of the Advance of Perihelion, the perturbations in eccentricity get an impossible value. These two are irreconcilable.

This has been abandoned later as stated in a paragraph on page 55, Vol. IX, Pr. Ac. Sc., India

§ 3 The method (2) is based on the assumption of a Differential Equation of the form

$$(1+\Sigma A_n r^{-n})\, dr^2+(1+\Sigma B_n r^{-n})\, r^2 d\theta^2-(\Sigma C_n r^{-n}-v^2D^{-2})\, D^2dt^2=0$$

where the constant D is not specified, and v is the initial velocity at a point $(r,\ \theta)$. By dividing the expression by $r^4\ d\theta^2\ (1+\Sigma A_n r^{-n})$ it becomes :

$$\left(\frac{dr}{r^2 d\theta}\right)^2+\left(1+\sum_1^\infty\frac{E_n}{r^n}\right)\frac{1}{r^2}=-\frac{D^2}{(r^2\dot\theta)^2}\sum_1^\infty\frac{F_n}{r^n}+\frac{v^2}{(r^2\dot\theta)^2}\left(1+\sum_1^\infty\frac{G_n}{r^n}\right)$$

Putting $r^2\dfrac{d\theta}{dt}=h$, a constant for planetary motion and $r=\dfrac{1}{u}$,

$$\left(\frac{du}{d\theta}\right)^2+\left(u^2+\sum_1^\infty E_n u^n+\cdot\right)=-\frac{D^2}{h^2}\sum_1^\infty F_n u^n+\frac{v^2}{h^2}\left(1+\sum_1^\infty G_n u^n\right)$$

Differentiating with respect to θ and dividing by $2\dfrac{du}{d\theta}$ we get:

$$\frac{d^2u}{d\theta^2}+u=-\tfrac{1}{2}\sum_1^\infty(n+2)\ E_n u^{n+1}-\tfrac{1}{2}\frac{D^2}{h^2}\sum_1^\infty nF_n u^{n-1}+\tfrac{1}{2}\frac{v^2}{h^2}\sum_1^\infty G_n n u^{n-1}$$

Dr. Sir Shah Sulaiman has deduced his equation from this by

(1) neglecting E_n, F_n for $n>1$, $G_n\geq1$

(2) putting $-\dfrac{D^2F_1}{2h^2}=\dfrac{GM}{h^2}$

(3) putting $-\frac{3E_1}{2}=\frac{3GM}{D^2}$

In the above deduction,

(*a*) nothing is said about the constant D except in putting $-\frac{3E_1}{2}=\frac{3GM}{D}$ where D is put equal to c, and it is assumed that the expression $\frac{6\pi\mu^2}{c^2h^2}$ is correct. In fact, doubt has been put upon this expression in pages 54—55, Vol. VI, by Sir Shah Sulaiman himself;

(*b*) $r^2\frac{d\theta}{dt}$ has been put equal to h which contradicts the theory of finiteness of velocity of Gravitation;

(*c*) terms containing E_n; F_n $(n>1)$, G_n $(n\geq 1)$ have been neglected;

(*d*) the identical equality of A_n and B_n on the assumption of symmetry as in Chapter XII, gives $E_n\equiv 0$, for all values of n, which makes the equation only $u_{\theta\theta}+u=\frac{\mu}{h^2}$ But this symmetry has been taken to be incorrect on page 86, Vol. VII, Pr. Ac. Sc., India, without any good reason;

(*e*) if the finiteness of the velocity of Gravitation be taken correct, as is fundamental in the theory, the Polar Differential Equation must be **some function** not only of dr, $rd\theta$, dt and the initial velocity, but also *of the initial radial and transverse velocities separately taken* **equated to zero.** This necessary fact obviously makes the assumed equation wrong.

§ 4. In the method (3) the equation of energy taken is

$$(1+f_1)\left(\frac{dr}{dt}\right)^2+(1+f_2)\,(r\dot{\theta})^2=c+\frac{2\mu}{r}\,(1+f_3)$$

which the case $f_1=f_2=f_3=0$ gives Newton's form, and the equation

$$\frac{d^2u}{d\theta^2}+u=\frac{\mu}{h^2}+\frac{3\mu}{D^2}u^2$$

is deduced by the method of the previous section by ignoring terms and assuming the accuracy of the expression $\frac{6\pi\mu^2}{c^2h^2}$.

Hence, all the objections stated above hold good for this method also. And since this method too ignores the initial radial and transverse velocity as the variables together with r in the f's, it also is wrong, and the equation deduced inaccurate.

§ 5. In method (4) the Potential Function is taken to be:

$$\frac{M}{r}+\frac{Mh^2}{D^2}\frac{1}{r^3}$$

(from para 6, § VII, Ch. XVI, by the integration of $-\frac{6GM}{r^2}\left(1+\frac{3h^2}{c^2r^2}-\cdots\right)$

and in analogy with the famous formulæ of retarded electric potential of Lienard Wiechart $\dfrac{\varepsilon}{r\left(1-\dfrac{v_r}{c}\right)}$ the value of the retarded gravitational potential comes out to be

$$\left[\frac{M+\dfrac{Mh^2}{D^2}\dfrac{1}{r^2}}{r\left(1-\dfrac{Vr}{D}\right)}\right]=\frac{M}{r}+\frac{Mh^2}{D^2}\frac{1}{r^3}+\frac{M}{2D^2}\frac{d^2r}{dt^2}+\ldots\ldots$$

whence by differentiation, with respect to r, the radial acceleration is found to be

$$-\frac{M}{r^2}-\frac{3Mh^2}{D^2}\frac{1}{r^4}.$$

This deduction has been used to seek to unify gravitational phenomenon with that of light and therefore with Electricity. The obvious mistake here is the assumption of the Potential to be equal to $\dfrac{M}{r}+\dfrac{Mh^2}{D^2}\dfrac{1}{r^3}$ which is incorrect due to:

(i) giving no transverse acceleration $\left(\text{for } \dfrac{\partial}{r\partial\theta} \text{ of this} = 0\right)$ which is inconsistent with the theory of finiteness of velocity of propagation of gravitational influence;

(ii) its derivation from the expression

$$-\frac{GM}{r^2}\left(1+\frac{3h}{c^2r^2}-\ldots\ldots\right),$$

which with all formulæ of §VII, Chap. XVI, depend upon the equation

$$\ddot{r}-r\dot{\theta}^2=-\frac{M}{r^2}-\frac{3\mu h^2}{D^2}\frac{1}{r^4}$$

which has been shown to be incorrect in the three preceding sections.

II

Michelson-Morley Experiment

§1. In §VII, Chapter V, on the assumption of the accuracy of De Sitter's test of binary stars, and Majorana's experiment with light from moving sources and reflected from moving mirrors, the Michelson-Morley experiment is sought to be explained. It is remarked that, "The assumption in Relativity that a right-angled triangle consisting of a solid sheet B′ NA can move in the direction AN with velocity

v in such a way that B′ N does not change, angle B′NA does not change, the side AN contracts to AN $\sqrt{1-\frac{v^2}{c^2}}$ and yet side AB′ contracts to AB′ $\sqrt{1-\frac{v^2}{c^2}}$ while A″ B′ does not rotate and B′ remains the common point of AB′, and NB′, for there is no reason why AB′ should rotate unsymmetrically round one point B′ only."

This involves the inaccuracy that "the contraction hypothesis is the same as Relativity hypothesis." In fact, on the contraction hypothesis, we change the length of a body by changing its motion. On the Relativity assumption we change the form of our equations by changing our mind; on the contraction hypothesis, a measuring rod or a clock undergoes an intrinsic physical change when its velocity is changed; on the Relativity hypothesis a change of velocity of the instrument is a conceptual process involving no intrinsic physical change. The contraction hypothesis can explain Michelson-Morley's experiment, but cannot explain the results of the experiments of Kennedy-Thorndike. No such difficulty is experienced by the Relativity hypothesis which, in fact, has been defined by Jeans (Page 597) in his Mathematical Theory of Electricity and Magnetism as follows:

"Systems of equations, or natural laws which are such as to make it impossible to determine absolute motion may be said to satisfy Relativity Candition."

This and some recent results have been discussed in an Article "On the interpretation of the Michelson-Morley and Kennedy-Thorndike Experiments" in the *Phil. Magazine Journal of Science*, Vol. 27, No. 185, pp. 693—702, June 1939.

§2. It is remarked on page 255, §VII, Chap. V, that

"It is also the fact that light from AB′ when received at B′, which is moving with velocity v is shifted forward by an angle $\sin^{-1} v/c$ owing to the Principle of Aberration already explained and behaves as if it came from AB′ where $AB'A=\alpha$. If, therefore, the eye-piece remains fixed so as to receive only the light coming along AB′, the component of the velocity of light along AB′ is reduced to $c_1 = c \cos\alpha = c\sqrt{1-\frac{v^2}{c^2}}$. It is this component which is reflected and travels along B′A″."

The Principle of Aberration is a correction applied *for* a system to which light is coming from a different place and hence the fact that light from AB′ behaves as if it came from AB′ is only true for a system bound with the mirror, and obviously there is no observer bound with the mirror.

The assumption that it is only the component $c \cos \alpha$ that is reflected implies that the component $c \sin \alpha$ is destroyed; but, for classical Dynamics of Newton, there must be some force to destroy some velocity, if it is assumed that component $c \sin\alpha$ is destroyed. Where is the force or Impulse that did it?

If Majarona's experiment be right, then two things are clear:

(i) Light is independent of the velocity of the source.

(ii) Reflection of Light is independent of the velocity of the moving reflector.

Hence, the reflected component must be c and not $c \cos \alpha$ The idea of the independence of velocity of Light produced on earth, in order to explain the null result of Michelson-Morley experiments, has been abandoned as stated on page 85, Vol. VII, Pro. Ac. Sc., India, and it is thought that light from non-terrestrial sources will have a velocity different from that from terrestrial sources.

III

§ 1. Relative Velocity

The symbol v in the Relative Velocity formulæ of Dr. Sir Shah Sulaiman and Prof. Einstein have two distinctly different significations; for the former, this v has different values for different experiments and has evidently no mathematically accurate expressions, but has only approximate experimental values. The idea of Relative Velocity has been introduced in Jean's 'Electricity and Magnetism' (page 599) as follows:

"677. The simplest case of rotation of axes occurs when every point moves parallel to one of the coordinate planes, say (x, τ). Then the formulæ for transformation assume the form

$$x^1 = x\cos\theta + \tau\sin\theta$$

$$\tau^1 = \tau\cos\theta - x^1\sin\theta$$

$$y^1 = y; \qquad z^1 = z$$

To determine what physical meaning is to be attached to θ we notice that when $x^1 = 0$, $x = -\tau \tan \theta$, $x = -$ ic t $\tan \theta$

Thus a point which the experimenter S regards as moving along the axis of X with velocity $-ic \tan\theta$ will appear to S′ to be at rest. *In other words, the axes of S′ move relative to those of S with velocity* $-ic \tan \theta$ *along* X *axis*"

Thus, $v = \dfrac{v^1 - u}{1 - \dfrac{v'u}{c^2}}$ is a definite expression not varying with different experimental methods

Dr. Sir Shah Sulaiman writes on page 247, Vol. IV,

"It is a fallacy to suppose that the coordinates are measured when the two systems are alternately at rest."

But this has nowhere been assumed in Relativity. It is implied in the Principle of Equivalence that the units of length and time are automatically so adjusted that

the relative velocity measured in the above sense by one system is exactly equal and opposite to that measured by the other.

The formula

$$\frac{v}{v^1-u}=\frac{1-\frac{v'}{D}+\frac{u}{D}}{\left(1-\frac{v'}{D}\right)1+\left(\frac{u}{D}\right)}$$

is based on the assumption of the result which follows :

"A is wrongly assumed to be at rest and B moving with relative velocity $(v'-u)$ or it is wrongly assumed with Newton that the result will be the same if A is reduced to rest by adding an equal and opposite velocity to B", (page 146, Vol. V, Pr. Ac. Sc, U. P.)

So far as I can see, it has never been assumed "wrongly", hence the above formula is not applicable to practical purposes. The same principle has been applied also to Chap. V, § 2.

§ 2. *Solution of the Diff. Equation*

$$\frac{d^2u}{d\theta^2}+u=\frac{\mu}{h^2}+\frac{3\mu}{c^2}u^2$$

by Sir Arthur Eddington.

Objection has been raised by Dr. Sir Shah Sulaiman on the method applied to give the expression for the advance of the perihelion from the solution

$$u=\frac{\mu}{h^2}\{1+e\cos(\theta-3k^2\theta-\omega)\}$$

since this equation satisfies

$$\frac{d}{d(\theta-3k^2\theta)}\quad\frac{du}{d(\theta-3k^2\theta)}+u=\frac{\mu}{h^2}$$

which is not identical or even approximately identical with the given equation (Chapter XVI, § ii).

But the same objections apply to the method used by Dr. Sir Shah Sulaiman in his deduction of the solution of his equations in Chapter I.

But the expression for the advance of perihelion as deduced by Sir Arthur from the above solution is correct up to the necessary degree of approximation; and since the perturbations in the major axis and eccentricity have nowhere been used in later calculations this objection has got no force.

§ 3 (*a*). The approximate Diff. Equation derived from Newtonian Mechanics with all corrections have so far been noticed, though applicable to planets, does not give any conclusive value of the advance of perihelion. But it is not applicable to Light particles if it is asserted that $D=c$. The full formulæ for accelerations are not easily adaptable to give correct conclusive values of the Deflection of Light.

Also the assertion of the equality of D and c makes the effect of gravitation on the light particles from the Sun (if $\frac{d\theta}{dt}=0$) nil. Hence, the Spectral shift is uncertain.

§ 3 (*b*) In later parts of this theory applications to various problems, of the equation of the orbit and the expression for the radial acceleration have been shown.

The cohesive force between atoms (§ viii, Chapter XVI) have been deduced by the assumption of the accuracy of applicability of gravitational formulæ (of § vii, Chapter XVI) to the electric problems of somewhat similar character; the gravitational formulæ themselves being corollaries to the equation:

$$\frac{d^2r}{dt^2}-r\left(\frac{d\theta}{dt}\right)^2=-\frac{\mu}{r^2}-\frac{3\mu h^2}{D^2}\frac{1}{r^4}$$

which has as yet no conclusive proof.

§ 3 (*c*). The applicability of the later parts of the theory contradicts results of Chapter I, so that it is irreconcilable with the finiteness of the velocity of gravitation, while the later parts are inconclusive due to the uncertain constant D having no physical significance, for it has been nowhere identified with the velocity of gravitation and it has been arbitrarily put $=c$ to get the expression $\frac{6\pi\mu^2}{D\,h^2}$ for the advance of perihelion.

Thus, while the uncertain later parts of the theory must abandon any idea about the velocity of gravitation, the former chapters must necessarily contradict the accuracy of the theory.

SULAIMAN'S REPLY

Mr. Roy's paper raises so many different points that a detailed discussion would make the reply very much longer than the criticisms themselves. They are taken up briefly in their order.

I

Para 1

As regards the accusation of "inconsistency," "contradiction" and "unreasonable discarding of the first method," I may point out that the difference lies in the retention and the non-retention of first order terms. The fundamental basis of the finiteness of gravitational velocity, which alters the Newton's orbital equation, has remained the same throughout.

In the *early* Chapters submitted up to August, 1935, in which the first method of ordinary Dynamics had been adopted, all first order terms were as a first attempt retained. The result was ultimately found to be twofold: (1) the equations became more cumbersome with higher approximations, and (2) there was a large residue of secular acceleration which could be counteracted only by a resisting medium. It was however pointed out even on that date (Chapter VIII, Part 10, page 130) that the first order terms should really be compensated for. Accordingly this method was not adopted in any paper after August, 1935.

The *second* method (Chapter XIII, Sec. II, pages 275—7, August, 1936) was based on the postulate of the path being a geodesic, and differed from Einstein's method mainly (1) in the deduction of ds^2, (2) in ds not becoming zero for light velocity and (3) the constant of velocity in the orbital equation being the velocity of gravitation itself, as the velocity of light as such has no significance. This method may be regarded as the 'rigorous' method and stands till to-day. Indeed the same result has been obtained by me from a slightly different line of approach in a paper which has already been accepted for publication in the *Philosophical Magazine*, 1940. This second method does not involve any first order terms at all. Mr. Roy has *not* criticized its validity.

The *third* method adopted by me was called an alternative method, and may be regarded as the 'empirical' method. Rejecting Newton's assumption that the orbital equation remained unaltered no matter how fast the object was moving, the method was based on a guess: What should more appropriately be the next approximate form of the differential equation? Such forms were considered in Chapter XIII, pages 277—9 (August, 1936), Chapter XV, App., pages 86—7 (July, 1937) and also in Chapter XVI, pages 36—38 (October, 1938). It will be noticed that in all these forms the extra velocity terms were by way of precaution retained. As will appear from the Note submitted to the Academy of Sciences on 11th July,

1939, which will be incorporated in an Appendix to the next paper, I came to the conclusion in this year that the difference from Newton's form should come in entirely in the acceleration and not at all in the instantaneous velocity, and that therefore the simplest and most appropriate form of the new equation must be

$$\left(1+\frac{\mu}{D^2}\sum_1^{\infty}\frac{A_n}{r^n}\right)\frac{d^2r}{dt^2}-\left(1+\frac{\mu}{D^2}\sum_1^{\infty}\frac{B_n}{r^n}\right)r\left(\frac{d\theta}{dt}\right)^2=-\frac{\mu}{r^2}\left(1+\frac{\mu}{D^2}\sum_1^{\infty}\frac{C_n}{r^n}\right)$$

The reasons which have convinced me are:—

(1) In the parallel case of a moving source, the effect of the retarded potential is only of second order (Chapter XVI, pages 53—5).

(2) The explanation is that a potential field already exists at all points at which the moving object arrives.

(3) This tallies with (*a*) astronomical observations, which fail to detect any first order effect, (*b*) the experimental fact that electromagnetic induction is produced only when the current is varying and not at all when it is steady, and (*c*) with Einstein's own assumption that physical laws remain unaltered in the case of uniform, unaccelerated relative motion.

Even this is a mere approximate and empirical form; and if anyone can suggest a better form I would welcome it.

PARA 2 (A), (B), (C), AND (D)

Mr. Roy concludes that according to the first method (where first order terms were retained) the value of the advance of perihelion comes to $\frac{3\pi\mu^2}{D^2h^2}$.

As would appear from Pr. Nat. Ac. Sc., Vol. 6, Part I, page 54, both Mr. A. N. Chatterji, who had kindly checked the evaluation, and myself were aware before October, 1935, that if first order terms are retained then for higher approximations the value of the advance was less than that calculated by Newcomb. I had left it at that for the following reasons:—Newcomb's value is now about 50 years old. Following Le Verriers he had unfortunately assumed that the corrections to the annual mean value of Mercury in longitude were the same for both the November and May transits, but it is now known that the mean epochs of these two sets of transits differ very substantially. Grossmann actually showed that with the necessary correction the value dropped to 25″·6, which is very nearly equal to $\frac{3\pi\mu^2}{D^2h^2}$. The uncertainty is so great that von Gleich has gone to the length of maintaining that the supposed excess of motion does not in fact exist. [Science and Culture, Vol. I, January, 1936.]

III

Relative Velocity

Para 1

The sole object of considering relative velocities in Chapter VII (August, 1935) was to show that just as it is impossible to measure exactly absolute velocities, so it is equally impossible to measure relative velocities exactly. In practice relative velocity cannot be measured without employing a messenger who travels to and fro, and even that would not determine the absolutely exact relative velocity. There can in fact be different methods of measuring apparent relative velocities, and it was shown that they give different results. This was the only object of this Chapter, and so none of the formulæ obtained therein has been used in any subsequent paper.

Para 2

My only objection to Eddington's solution was that it was the solution of a different differential equation. This cannot be disputed. It was never suggested by me that the value of the advance of perihelion was itself wrong. Indeed I myself gave an explanation why it turns out to be right (Phil. Mag., December, 1938, page 987) My own fuller solution yields the same result.

Para 3 (*a*)

I maintain that the law of gravitation $-\frac{\mu}{r^2}-\frac{3\mu h^2}{D^2}\cdot\frac{1}{r^4}$ propounded by me gives correct values for (1) the advance of perihelion, (2) the deflection of light from stars past the Sun, (3) the spectral shift of light from the centre of the Sun, and (4) the spectral shift of light from the edge of the Sun. The values of the second and the fourth differ substantially from Einstein's and have been tested by observation.

Para 3 (*b*)

The cohesive force between atoms is a necessary deduction of the law, without any new postulate.

Para 3 (*c*)

The significance of D has already been explained. The success of the new theory depends on the two main predictions which differ from Einstein's. The latest Solar eclipse observations of both confirm my results. Dr. Royd's value of the spectral shift of light from the edge of the Sun is 100% more than Einstein's, and Prof. Michaïlov's value of the deflection of light is more than 50% in excess of Einstein's.

THE RADION AND THE ELECTRO-MAGNETIC WHIRL II

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Communicated by Sir Shah Sulaiman

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SUMMARY

The author compares Sir Shah Sulaiman's Radion theory according to which Light and Matter are formed by rotating dipoles, "binary stars," called Radions, and his own Whirl theory according to which Light and Matter are formed by certain axially symmetrical systems of Maxwell e.m. waves, which he called e m. whirls or simply Whirls

This comparison of two theories is preceded by the discussion of the conditions of adequateness of a physical theory. Two schools of mind can be distinguished in this question According to the one the purpose of Science is to ***explain*** the unfamiliar experience in terms of the familiar one by means of visual images taken from the latter, which the author called generally "models." According to the other, such an explanation is unattainable, and, therefore, the Science can only ***correlate*** the experience, and this can be done by an artificial system of mathematical symbols with ***ad hoc*** invented rules of operation.

Sir Shah and the author both associate themselves with the first school, but they choose their models differently.

The author gives the reasons why, in his opinion, the explanation of the physical world by means of models is important not only for the Science itself but also for the general progress of mankind, and why such an explanation should be attainable.

Then, the author gives the summary of Sir Shah's theory, mainly in Sir Shah's own words, and summarizes the general foundations and the principal conclusions of the Whirl theory. He recalls that the Whirl theory of Light and Matter is entirely based upon Maxwell Electro-dynamics, and that according to this theory the classical, quantum and wave mechanical, and relativistic properties of Light and Matter are the necessary corollaries of the electro-magnetic properties of the whirls.

Further, the author quotes verbatim Sir Shah's criticism of the whirl theory and gives the reasons why he considers this criticism invalid.

The author thinks that the chief advantage of the whirl theory is the singleness of its unifying principle; while Sir Shah must use electric charge, ***and*** inertial mass, ***and*** the Maxwell e.m. field, as independent fundamental conceptions, in the whirl theory the Maxwell Electro-dynamics in free space is the general foundation of the whole theory.

Then the author finds in the formal part of Sir Shah's theory certain difficulties which he thinks to be hardly surmountable, namely, for the description of the e.m. field of his Radions. Sir Shah uses the same solution of the Maxwell equations as the author himself used for the e.m. whirls ("the Japolsky solution" as Sir Shah calls it), but this solution does ***not*** correspond to the boundary conditions presented by Sir Shah's Radions

In conclusion, the author expresses his appreciation of Sir Shah's contribution as a research in a new field. Especially he points out the importance of the part of Sir Shah's work where he

derives the Schroedinger and Heisenberg equations from the de Broglie and Planck relationships, which are the necessary corollaries of the "Japolsky solution" which Sir Shah and the author are both using for their respective theories.

PART II

In the world of Whirls the Einstein Special and General *Principles* of Relativity* must be observed on the basis of the Maxwell Electro-dynamics, while the General Theory of Relativity† should depend on the actual structure of the system.

The Maxwell Electro-dynamics require that the displacement currents, the density of which is measured by the time rate of change of the electric vector, should electro-dynamically behave exactly in the same way as the so-called "conduction currents."

This means that they must produce the same electro-magnetic field and develop the same ponderomotive forces. The first property is expressed by the Maxwell equations (4·1), the second results in certain limitations in their solutions, which is equivalent to certain initial and boundary conditions referred to at the beginning of this section.

The well-known additive properties of linear differential equations mean that, as far as it concerns the Maxwell equations, by themselves the whirls can move independently of each other. When, however, we introduce the ponderomotive forces between the displacement currents, calculated in the usual way,‡ we find certain limitations in the motion of Whirls, that is to say, in the solutions of the Maxwell equations, which we can physically accept.

Calculation of the ponderomotive forces between the whirls of similar structure leads to the following *average* results :

(1) Whirls of equal size repel each other according to the inverse square law.§

(2) Whirls with a large size and mass ratio *attract* each other following the *inverse square* law when the distance between their centres is large in comparison with the wave lengths corresponding to their frequency, but this attraction transforms into a repulsion in accordance with the *inverse cube* law when this distance is very small ||

Generally speaking, this force of attraction is *not* equal to the force of repulsion but depends upon the size ratio of the whirls.

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*That is to say, the impossibility to discover an absolute motion, translatory as well as rotary. *Phil. Mag.*, II, pp. 458—465.

†That is the suitable four dimensional world geometry. *Phil. Mag.*, XX, p. 44.

‡*Phil. Mag.*, XX, pp. 644—648.

§*Phil. Mag.*, XX, p. 683.

||*Phil. Mag.*, XX, p. 664 ; and XX, pp 554—556

These properties of Whirls suggest that the electron and the proton are forms of Whirls. Then all the properties of elementary corpuscles can be explained on the basis of Maxwell electro-dynamics without any additional hypothesis.

From the experimental fact that the repelling forces between the electrons and between the protons are equal, we find, again on the basis of Maxwell electro-dynamics, that their masses must be in proportion, and sizes in inverse proportion, to their frequencies.*

Further, on the same basis, the force of attraction between the electron and the proton can be equal to the force of repulsion between the electrons or between the protons if, and only if, the mass ratio of the proton to the electron is about 1830. Strictly speaking, within theoretical limits of accuracy of the actually employed method of calculation, this should be true within about 3%, probably less. The latest experimental result for this ratio is about 1838.†

Thus, the actual mass ratio between the proton and the electron is determined by the stability condition of inter-corpuscular structures, which means that this ratio could be evolutionary arrived at by natural selection.

The fact that there exists a limited number of types of particles with different energies can be attributed to the tendency for equi-partition of energy, this tendency being the stronger the nearer are the sizes and the structures of the particles.

On the other hand, the equality of angular momenta (*i.e.*, the equality of the Planck constant) for each particle can be explained by the well-known tendency of equi-partition of angular momenta.‡

To every type of Whirl corresponds another type, of exactly the same energy, in which the magnetic lines of force are substituted for the electric lines of force and *vice versa*.§

Therefore, to the electron and the proton two more types of particles will correspond. These we can call the "magneto-electron" and the "magneto-proton" respectively.

Generally, we call two particles in which the electric and the magnetic lines of force are mutually substituted "contra-polarised" particles in contradistinction of "co-polarised" particles which are quite similar in structure, although may be different in size (like, for instance, the protons, the electrons, and the protons *and* the electrons).

The laws of force between the co-polarised Whirls were given above.

**Phil. Mag.*, XX pp. 656 and 692.

†*Phil. Mag.*, XX, pp. 684, 690, 692 and 699.

‡*Phil. Mag.*, XX, pp. 642–644.

§*Phil. Mag.*, XX, p. 696.

The theoretical investigation of forces between the contra-polarised Whirls shows that

(1) When they are of equal size and mass they *attract* each other according to the *inverse cube* law,* which at very small distances transforms into the repulsion according to the inverse fourth degree law. Therefore the interaction is negligible at large distances but can be very strong at small distances.

(2) When they are of largely different sizes they *attract* each other according to the *inverse square law*, which at very small distances transforms into *repulsion* in accordance with the *inverse cube* law.†

This force, however, is much smaller than the force of attraction between the co-polarised particles.

The magneto-electron can be identified with a positron; the magneto-proton with a particle which is by its nature very difficult to observe owing to very small force of interaction with the electrons or protons at large distances.

However, both these contra-polarised particles must play a very important part in the structure of the neutron and the atomic nuclei ‡

This assumption has been applied to the structure of the neutron (which, according to the present theory, is a complex particle) and of the light nuclei up to $_2He^4$, including all the isotops (altogether 6 items) §

Not only plausible stable structures of these entities were obtained on this basis, but also the result of calculation of their masses proved to be in remarkable agreement with Dr. Aston's observations ||

It should be noted that in these calculations the corrections to the laws of forces at small distances were taken into account.

It has been found on the basis of Maxwell electro-dynamics that when the Whirls come into a combination their masses must change, and the resulting from this change in "packing" energy and the "mass difference" were also taken into account in the calculations.¶

The atomic phenomena are explained by the whirl theory in the same way as by "Classical" Atomic Physics, for in these phenomena, the inter-corpuscular distances are comparatively large, and, therefore, the corrections to the inverse square law of forces which follow from the Whirl theory, are too small to be taken into account. On the other hand, the general quantum properties of the Atomic Components which

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**Phil. Mag*, XX, p. 686 and XXII, pp. 539—546.

†*: hil. Mag.*. XX, pp. 685-686.

‡*Phil. Mag.*, XXII, pp. 564—572.

§*Phil. Mag*, *loc. cit.*

||*Phil. Mag*, XXII, p. 579.

¶*Phil. Mag.*. XXII, pp. 556—565.

are postulated by "Classical" Atomic Physics, follow from the above-mentioned intrinsic electro-dynamical quantum properties of the Whirls.*

The "spin" and the Selection Rule, or, at any rate, a very small probability of deviation from the Selection Rule, also follow from the Whirl theory.

The agreement of the actual mass ratio between the proton and the electron, and of the masses of the neutron and light neuclei, obtain from theoretical calculation, with the experimental data, gives altogether seven independent numerical evidences in favour of the Whirl theory, apart from its consistency with the principal, classical, and Quantum, and Wave Mechanical relationships, so far as the latter are experimentally confirmed.

Needless to say, the singleness of the unifying principle should be regarded as a favourable feature in itself.

Since the mass ratio between the proton and the electron can be calculated theoretically, the number of the independent world fundamental constants which must be obtained from the experiment reduces to four. These can be taken as the speed of light c, the Planck constant h, the mass of one of the particles, say the proton, m, and the force constant which can be defined from the ponderomotive forces, say the charge of the particles, e.

It follows from the above that a purely electro-dynamic representation of the Universe, without discontinuities in the electro-magnetic field, is as least promising. Consequently the what I called "defeatism," the renouncing of any possibility of explaining the Universe in terms of familiar macroscopic experience, is at least premature.

The Whirls are not solid. They interpenetrate, but they are still three-dimensional, and, owing to Faraday representations of e m. fields by lines of force, they are, nevertheless, *visual models*, which, as I said before, must, at least for the present generation, give the same satisfaction as the charged billiard balls in miniature. Moreover, this satisfaction should be more complete for the billiard balls with their elastic properties present for us a *very* complex system. On the other hand, the constancy of charges in the accepted sense contradicts all our macroscopic experience, for we know that the electric charges *always* change with the change of mutual position of the charged bodies.

Besides . . , . charges, *and* waves, *and* masses appear to be too many independent fundamental features. The wave function and similar mathematical artifices may correlate and perhaps formally unite these conceptions, but they do not seem to merge them organically to our mind's satisfaction, for which it is necessary that our vision should occupy in our conception of the Universe "a position which would be adequate to its general importance in our mental life."†

Phil. Mag., XXII, pp. 556–565.

†See above.

In conclusion, of this section, I would like to say a few words about the determinism in Physics from the point of view of the Whirl theory.

Strictly speaking, the Whirl theory becomes deterministic if, and only if, the initial and the boundary conditions of our Universe are fully known. These conditions, however, can be superseded by the laws of forces, owing to the stability of the Whirls.*

But the use of the laws of forces introduces certain practical limitations to the deterministic interpretation of the experimental result. These limitations can be roughly divided into three categories:

(1) The limitation of the number of data regarding the speeds and positions of the Whirls, which is necessary to calculate the forces. The limitations of this kind, resulting from the lack of data, can be called "macroscopic indeterminancies."

(2) Limitations due to the lack of knowledge of momentary state of each Whirl.

The laws of forces are only average laws. They deliberately leave out of account, not only momentary perturbations in the structure of each Whirl, but even deviations in the orientation of their axes from the average. This is covered by complex rapid fluctuations which I have called "the vibrational state."†

Therefore, in the method of our interpretation of the observable phenomena, it may prove expedient to represent the laws that govern them as "probability laws" instead of "deterministic laws."

Among the eventualities of the vibrational state can be, for example, a short-time reverse of the orientation of the electron, which may result in its attraction to another electron instead of repulsion.‡ Then the electron may appear as a positron. This momentary positron should be distinguished from the magneto-electron, which can be regarded as a fundamental positron.

These limitations of determinism can be called "microscopic indeterminancies."

Since the energy of any oscillation in the vibrational state is equal to hν this microscopic indeterminancy will be consistent, at least for practical purposes, with the Heisenberg "Indeterminancy Principles."

(3) The forces between the Whirls, so far calculated, are the forces between the Whirls of similar structure, and particularly with equal number n of waves around the axis (number of pairs of poles).§

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*See above in this section.

†*Phil. Mag.*, XX, p. 670.

‡*Phil. Mag.*, XX, p. 701.

§See above.

The Whirls with different n interact very little. Our body and nerve system consist of electrons, protons, magneto-electrons and magneto-protons. Thus, the Whirls with n differing from the n of these particles (or as we assumed $n=1$)* would be very unlikely to be directly observable by us if they existed. Logically, however, there is no reason why such particles should not exist.

In certain exceptional circumstances the Whirls of different number of poles can interact and, therefore, if the particles with n differing from that of the known particles did exist, they could produce effects which it might be impossible to explain.

The indeterminancy proved by the influence of unobservable whirls can be called "transcendental indeterminancy."

Thus the whirl theory is essentially deterministic, that is to say, causal connection between phenomena is one of its fundamental corollaries (not postulates), but, owing to the essential limitations in the knowledge of the data, it admits certain elements of indeterminancy which can be legitimately embodied in the formulæ for the correlation of experimental data.

Sir Shah Sulaiman's Criticism of the Whirl Theory

Sir Shah writes†

"(1) The Physical nature of the whirls is not known; while radions are like binary stars, revolving and moving forward.

(2) A rotating wave or whirl requires a medium for its propagation, and a fluid medium too; it is awkward to fill the whole space with fluid medium in order to find means for light to come from any single star. A radion can travel by itself through the void space; indeed a medium would obstruct it.

(3) A whirl may well expand and spread away; so some assumption has to be made for its retaining form and size during its passage through vast space. On the other hand, no such assumption as to the stability of a binary system is required, for the mutual attraction of the components will maintain their orbit.

(4) A whirl should create more and more whirls round itself in the medium and its energy would soon be scattered away. An isolated radion conserves its energy, until it meets an obstruction, it gets no chance for parting with any energy.

(5) It is not clear why a whirl of proton or electron should possess a characteristic mass. Another difficulty is that such energy or mass would have to be distributed all along its infinite length and singularities should not occur. No such difficulty arises in the case of discreet radionic units.

(6) It is difficult to see what happens when two whirls collide. If they are superposed, they should pass through. If not, then after collision the two infinite trains must scatter away; but it is difficult to conceive of a Compton scattering of

*Phil. Mag., XX, pp. 644 and 703.

†Sir Shah Sulaiman, *loc. cit.*, pp. 67 and 68.

two infinite waves approaching each other from opposite directions along the same axis. Radions can of course collide like billiard balls.

(7) It is doubtful whether without any charged particles forces acting on the field can at all be produced. The charged binary system will of course produce a field.

But these difficulties are not peculiar to Japolsky's 'whirls'. They are inherent in every system of waves, including those of "Wave Mechanics."

I shall try to answer Sir Shah's criticism point by point.

(1) The Whirls are certain definite forms of Maxwell e.m. waves. This is their physical nature. Maxwell e.m. waves constitute *the* fundamental conception of the Whirl theory.

On the other hand, Sir Shah's "binary stars" have a number of hypothetical features, by no means elementary. The chief feature is that they are charged and produce the Maxwell electro-magnetic field.* Thus Sir Shah must use three independent fundamental conceptions instead of one, namely, mass, charge *and* the Maxwell electro-magnetic waves. It is difficult to see, therefore, why the physical nature of Sir Shah's "binary stars" should be clearer than the physical nature of the Whirls.

(2) I am afraid that here Sir Shah's interpretation of Maxwell theory is not quite correct, for Maxwell electro-magnetic waves do *not* require any medium for propagation

(3) The Whirl cannot "expand and spread away." This is clear from its mathematical expression which, on the contrary, clearly represents a *stable* system of e.m. waves.

Here again Sir Shah falls, I am afraid, into a rather common error that "the energy of Maxwell e.m. waves must necessarily spread." In fact the most "popular" solutions of the Maxwell equations, like, for example, plane e.m. waves of constant amplitude, do *not* represent a spreading e.m. energy but an e.m. energy uniformly filling the whole infinite three-dimensional space. The energy at each point undergoes periodic transformation from the electric into magnetic form and *vice versa*, but its total average density remains constant. Equally the ordinary rotating cylindrical waves represent a stable system of e.m. waves and their energy does not spread. However, these waves, although convenient for an approximate analysis are *physically impossible*, because the total energy of the whole system of these waves must be infinite, in case of plane e.m. waves it is equal to ∞^3 while in case of continuous cylindrical waves it is equal to ∞^2. On the other hand, a stable "compound whirl"† which we call for brevity simply the whirl *is* physically possible because its total energy, although spread over the whole space, is *finite*.

***Ib. idem.*, p. 79

†*Phil. Mag.*, XX, pp. 446–451.

(4) The solution of the Maxwell equations, which represents the system of e.m. waves which we called the whirl, represents a single whirl and not the "whirl creating other whirls." Possibly a solution can be found which would represent the latter system, but even then it would not follow that a whirl *must* create other whirls.

Incidentally, I was unable to find a solution which would correspond to a "whirl creating other whirls" according to Sir Shah's interpretation, and Sir Shah apparently does not even attempt to show how to find it.

(5) I think it has been very clearly explained how the whirl possesses the inertial mass.* Since, by the nature of the whirl, its electro-magnetic energy E grows with the speed v, it is clear from the elementary mechanics that its mass $m = \frac{1}{v} \frac{dE}{dt}$. Further calculation shows that $E = mc^2$.

(6) Since the forces between the whirls can be calculated there is no difficulty in principle to solving the problem of their collision.

(7) The wording of this point is not very clear. If I understand Sir Shah correctly he is in doubt whether the ponderomotive forces between the whirls can exist. He does *not* explain the reasons for his doubts but refers to Dr. Boris Podolsky's paper in the *Philosophical Magazine*.†

However, the invalidity of Dr. Podolsky's criticism has been clearly shown by me in the addendum to his paper.‡

It was shown that Dr. Podolsky's doubts on the existence of the forces between the Whirls were based on a misunderstanding. He apparently thought that I claimed to derive these forces from the Maxwell equations, while in reality I derived them from certain limitations to the solution of the Maxwell equations, which are equivalent to certain initial and boundary conditions.§ In fact these limitations conform with the principle of electro-dynamic equivalency between the "conduction current" and the displacement current which is inherent in the Maxwell electrodynamics, although not in the Maxwell equations.

It has been further shown that Dr. Podolsky's criterion was inadequate and generally the proof of his proposition was invalid.

In these circumstances Dr. Boris Podolsky's evidence is hardly admissible in the present case.

**Phil. Mag.*, XX, pp. 456–458.

†*Phil. Mag.*, XXII, p.100s.

‡Although both papers appeared more than two years ago, my objections to Dr. Boris Podolsky's criticism have not been contested. In fact I do not think that they are answerable at all.

§See above.

Further, referring to my statement about the validity of the principle of relativity in the world of Whirls, Sir Shah writes* that the invariancy of the expressions for the electro-magnetic field in the moving Whirl

"can be wrongly interpreted as if for a system moving with a velocity the time expands and the length contracts. With due deference to the conclusion of Japolsky, *the real truth is that if a system is both rotating and moving forward with a uniform velocity, then vector quantities, which are subject to Maxwell's equations, do change, but can be wrongly assumed to remain an invariant if Lorentz transformations were applied. But this would not hold in the case of a simple translatory motion.*" (Italics by Sir Shah.)

Here, I feel, Sir Shah's criticism is based on a misunderstanding.

Of course, for the fixed observer the e.m. field does change, but this change cannot be observed when one moves with the system.

What I have shown is that if we accept the Whirl theory ("in the world of whirls") this apparent discrepancy is automatically explained on the basis of Maxwell Electro-dynamics, without the aid of any special arbitrary postulates.

Now if Sir Shah would prefer to take any system as *the* fixed system, there is no harm in that, but according to the Whirl theory this should be taken as a convention for no observation could neither prove nor disprove it. In Physics we deal only with phenomena which are observable, at least in principle. Therefore the statement about the reality of certain features, which *in principle* cannot be tested by observation, lie outside the scope of the physical side.

FORMAL DIFFICULTIES IN SIR SHAH SULAIMAN'S THEORY

In the previous section I gave the reasons why in my opinion the fundamental principles of Sir Shah's theory are more complex than of the Whirl theory, and, therefore, are less unifying.

Now I have to point out certain formal difficulties.

To represent the e.m. field created by elementary particles (like the electron and the proton) Sir Shah uses the "Japolsky's solution"† of the Maxwell equations but he ascribes this e.m. field to the charged binary stars.

**Ib idem*, p. 79.

†It is not quite right to call this solution by my name. It is true that I came to it independently and developed it in my own way from the physical picture of the e.m. field I visualized. Also I gave it a definite physical interpretation. However, from a purely mathematical point of view, the solution itself was known in a general form long ago. Only recently I found it in the H. Bateman's book "The Mathematical Analysis of Electrical and Optical Wave Motion on the basis of Maxwell Equations" (Cambridge Univ. Press, 1915, p. 72, formula (149). The amusing part is that this book was actually on my shelf when I wrote my paper, and I sometimes consulted it but noticed this general solution only when my paper on the Whirl Theory had already been in print.

Verily, we do not see things before we can comprehend them (see Section 2 of this paper).

It should be noted that the transition from this general solution to that which I required would be a longer process than integrating the Maxwell equations anew as I did. Besides it would be certainly less convincing (*Phil. Mag.*, XIX, p. 935).

However, to have the right of doing so, Sir Shah is obliged to prove that his charged "binary stars" correspond to the boundary conditions of the "Japolsky's solution." Sir Shah does not do so, and, in fact, it is difficult to see how he could succeed if he made such an attempt. For the "Japolsky's solutions" correspond to the Whirl with no discontinuities in the electric field ("charges"), that is to say, it corresponds to different boundary conditions. On the other hand, a given solution can correspond to one and only one set of boundary conditions.

The same objection applies to Sir Shah in "Simpler Physical Solution" of the rotational theory of light (see section 4 of this Paper). In this case his field corresponds to a *charged axis** and *not* to rotating dipoles, as his binary stars are.

There is another objection to Sir Shah's "Simple Theory." It could be easily shown that the total energy† of his field is infinite; in fact, it is ∞^2.‡ Therefore his field cannot physically exist.

CONCLUSION

After completing my critical work I must say that, in spite of all my objections to Sir Shah's theory and to his criticism of my own theory, I regard Sir Shah's paper as a very valuable contribution.

He made an attempt to overcome the difficulties of Modern Physics by an original theory, which is plausible at first sight. Although further analysis shows certain unsurmountable difficulties, the work still remains valuable for it investigates a new field.

Further, I think, Sir Shah made a very valuable statement that the "Quantum and Wave Mechanics" are "a mere rotational Mechanics" (Section VII).

As was first published in 1935§ and several times mentioned above, the Quantum relationships of the Whirl are due to its rotational properties.

Sir Shah goes further. He apparently thinks that *any* rotating system has quantum relationships. I am inclined to agree with him though I feel that his statement must be carefully verified. Still it remains important whatever may be the result of this verification.

From the Quantum and the Broglie relationships in rotating systems Sir Shah derives the well-known Schroedinger and Heisenberg equations (Section VII). This is very important, not only from his own point of view, but also for the Whirl theory.

I wish to thank Sir William H. Bragg, O.M., President, Royal Society, and the Hon'ble Sir Shah Sulaiman, M.A., LL.D., D.Sc., President of the National Academy of Sciences, India, for their kind interest in my work.

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*N. S. Japolsky, *Nature*, 137, pp. 663 and 1031 and Sir J. J. Thomsom, *Nature*, 137, p. 823.

†For the method of calculating such energy see, for example, *Phil. Mag.*, XX, p. 435.

‡By using Fourrier integral along the axis this can be reduced to ∞^1, as has been shown by Sir J. J. Thomson (*Nature, loc. cit.*)

§*Phil. Mag.*, XX and XXII, *loc. cit.*

SIR SHAH SULAIMAN'S REPLY

Dr. Japolsky's paper consists of two parts, first an excellent exposition of his own Electro-Magnetic Whirl Theory, and secondly some criticisms of my Rotational Theory of light and matter. As regards the first, I do not wish to say anything except expressing my admiration for the new line of approach which Dr. Japolsky has invented and the admirable results which he has obtained. I only wish to refer to his criticisms of my theory. I shall first take up his replies to my criticisms of his theory in their serial order, and then add replies to a few further points.

1) As to the physical nature of electro-magnetic waves, I have always maintained that without the assumption of an all-pervading medium through which waves can be propagated, the existence of waves can have no physical meaning I admit that I "belong to an earlier generation," but he makes me too old when he assumes that then "there was no wireless" (p 217). Being free from some modern prejudices I am in a better position to discern that talking of physical waves without a medium is meaningless. There are two and only two possible ways in which energy can be propagated through space, *viz.*, translation of corpuscles or conveying vibrations through a medium. The mediumless whirls admit of no possibility at all.

2) When I asserted that a rotating wave or Whirl requires a medium for its propagation and a fluid medium too, I was not interpreting Maxwell's theory, but stating a plain fact. Maxwell's theory does not profess to be based on the existence of a medium, and yet it is a wave theory. Indeed a medium would cause immense difficulties. That is the exact weekness of Maxwell's theory, and, for the matter of that, of Dr. Japolsky's theory as well.

3) Again I was not explaining Maxwell's electro-magnetic waves, but only pointing out that if there be a medium in which Whirls exist, then in view of the necessary uniformity of the structure of the medium, such Whirls must expand and spread away. In order to have a stable system of electro-magnetic waves, Maxwell's theory must reject the medium, but then it simultaneously makes the existence of the waves in itself impossible.

4) Similarly, when stating that a Whirl should create more and more Whirls round itself in the medium, I was not propounding any solution of Maxwell's equations, but was asserting that in a medium such a result would necessarily follow. This can be easily seen to be the effect of waves in air or water.

5) I had similarly emphasised that it was not comprehensible how a whirl should possess "a characteristic mass." In the first place, mass associated with imaginary waves, without a medium, is a contradiction in terms In the second place, without a postulate as to fixed quanta of energy, fixed inertial masses are

impossible. Such an assumed mass of a whirl ought to have infinite variations from zero to infinity, if there were a medium.

6) I still maintain that the collision of imaginary whirls is incomprehensible. Dr. Japolsky himself in the first part remarked that his whirls "interpenetrate" (p. 23). They must, therefore, pass through one another, in which case their collision to explain the Compton effect of scattering would be impossible.

7) I agree that Dr. Japolsky has sufficiently met Dr. Podolsky's objection Still the periodic transformation from the electric to magnetic form and *vice versa* in the field remains wholly unexplained. A rotating pair of point charges or even a rotating magnet would easily produce such an effect.

(*i*) Models are undoubtedly in disfavour. But scientists, who seek shelter behind such an excuse, really evade the question how energy can be propagated from one point to another in space without there being corpuscles or a medium. This is not at all a microscopic phenomenon, but one of a large macroscopic scale when light energy can come from distant nebulæ in some 150 thousand million years. (p. *215*).

(*ii*) My conception of binary corpuscles is really going one step further than the mere conception of electro-magnetic waves. It not only involves such waves, but also explains how they are actually created This is carrying the uniformity of structure in Nature a little deeper (p. *217*).

(*iii*) My conception of electrons, protons, etc., is not exactly of the same structure; I have treated them as rotating magnets, instead of one positive and one negative charge revolving round each other (p. *218*).

(*iv*) When illustrating "the real electro-magnetic field" Dr. Japolsky is compelled to compare it to "very rough sea," and cannot avoid a medium without which his waves would be incomprehensible (p. *202*).

(*v*) The singleness of the unifying principle can be obtained only by shutting one's eyes to the question how waves can exist without a medium. It may be that "at least for the present generation," these imaginary and unreal waves satisfactorily represent "visual model;" but I regret that for the older generation they can represent no visual models at all. Such models can be furnished only by the binary hypothesis (p. *23*).

(*vi*) There may be a "misunderstanding," but it is certainly not on my part. In all laboratory experiments to which Special Relativity formulæ apply, the observer, with the apparatus, is fixed to the earth. What I had meant to say was that the motion is really rotational, while the observer wrongly assumes it to be straight. Hence, the results appear to him to be subject to Lorentz transformations. The Whirl theory appears to be less complex simply because it ignores the old conception

of the medium without attempting to consider how waves can then at all exist without it. (p. *28*).

(*vii*) Boundary conditions become necessary in Dr Japolsky's solution because of the non-expanding whirls. No such difficulty really arises in my theory as the binaries themselves create the field. When the charges are finite, the intensity diminishes very really as one moves away from the axis of rotation (p. *27*). The difficulty, if any, can be only in the mathematical solution of the equations and not in the physical picture itself.

I am, however, grateful to Dr. Japolsky for his appreciation of my "contribution as a research in a new field" which he calls "very valuable" and the "importance of the part of my work" where I derive the Schrœdinger and Heisenberg equations from the de Broglie and Planck relationships. I need hardly say that I have published only two papers so far and, therefore, my theory is not yet sufficiently comprehensive, but has undoubtedly immense possibilities.

INTERMITTENT DISCHARGE IN MERCURY VAPOURS

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(Received on October 9, 1939)

SUMMARY

The apparatus consists of a cylindrical pyrex glass discharge tube with circular nickel electrodes. A reservoir of mercury is sealed to the tube to maintain the supply of mercury vapours.

The apparatus was exhausted with a Gaede's single stage all steel mercury diffusion pump, backed by a Hyvac, to a high vacuum and was then sealed off without degassing the electrodes and "baking" the glass walls. The temperature of mercury vapours in the tube was controlled by an electric furnace.

It was observed that, at certain temperatures of mercury vapours and the tube voltages, the discharge was intermittent. At any particular temperature the frequency of the glows was found to increase with the increase of the discharge potential and current. With the increase in the duration of glows, the interval between successive glows was also found to increase. The discharge, in most cases, started with some time lag.

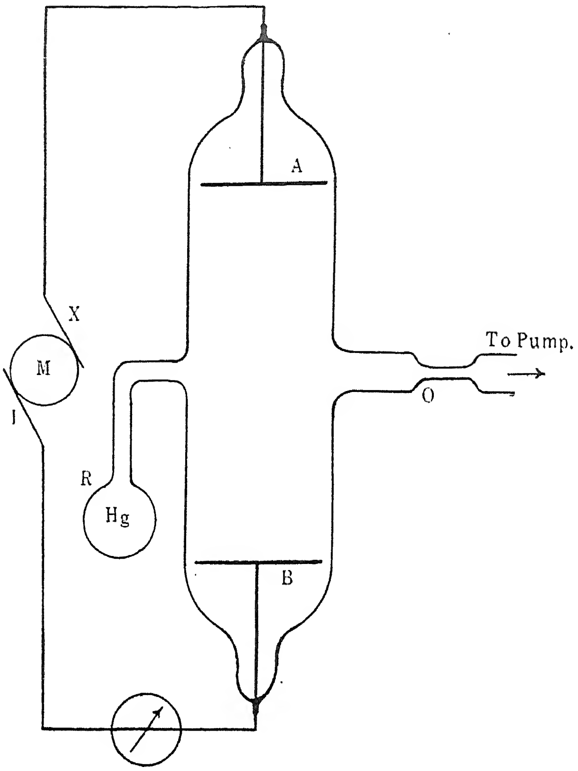
The electric discharge through gases at low pressures is, in general, intermittent, but the frequency of intermittence is very high and the discharge appears continuous unless examined by a rotating mirror. (1) Cases have been known when the frequency is small and the time between successive discharges is several seconds. (2)

We have observed an intermittent discharge of low frequency in mercury vapours.

Description of The Apparatus

The discharge tube is of pyrex glass, 3·8 cms. in diameter and 17 cms. in length The electrodes A and B are circular discs of nickel, cut out from the same sheet, each 3·6 cms. in diameter and 0·1 mm. thick. Tungsten wires, about 1 mm. thick, are spot-welded to the back of the electrodes, which are held firm in position in the tube, parallel to each other, by Tungsten-Pyrex-Seals. The distance between the two electrodes was about 13·5 cms. A reservoir, of pure mercury obtained from M/S Mercks, Germany, was sealed into the discharge tube, as shown in the figure at R.

The apparatus was connected through a capillary, to a single stage Gaede's all steel Mercury Diffusion Pump, backed by a Hyvac pump, and was exhausted to a high vacuum. The mercury reservoir was heated gently by a Bunsen burner for a few minutes under a high vacuum to expel absorbed gases from mercury.



The whole apparatus was also warmed with the Bunsen flame but it was never properly "baked". The diffusion pump was continuously kept running throughout the heating process and was left working for several hours after the heating was over. No liquid air was applied to the trap, sealed between the apparatus and the diffusion pump. After the discharge tube had been exhausted for several hours, it was sealed, under vacuum, at the capillary 'O'.

That the apparatus was vacuum-tight was tested by a leak-tester several hours after it was sealed off.

The discharge tube was placed vertically in an electric furnace, locally made, in which the temperature was controlled by regulating the current. The mercury vapours in the discharge tube could be thus maintained at any desired temperature.

The High Voltage for the discharge tube was obtained from an Evershed H. T. D. C. Motor Generator set M, and was measured with an Electrostatic Voltmeter.

The experiment was performed at different temperatures of Hg. vapours.

The results are given in the Tables below, with explanatory notes.

TABLE I

Temperature of Mercury Vapour 120° C.

No. of glow	Minimum voltage required to initiate the discharge	Voltage on the tube during the discharge in volts	Current of the discharge in M. Amps.	Duration of glow	Interval between successive glows.
I	1600—1700 volts	about 1500 v.	1·0	1 second.	
II	„	„	„	„	1 second
III	„	„	„	„	1 second
IV	„	„	„	„	1 second.
	1600—1700 volts	1250	6·0	continuous	

The intermittent discharge started after a time lag of a few minutes.

The intermittence continued for several minutes with almost equal intervals of glow and darkness. After some time the discharge became continuous, the voltage on the tube fell to 1250 V. The current was about 6 milliamperes to start with, but gradually fell to 4 milliamperes, the voltage remaining constant. Further slight decrease in the voltage put the discharge out and it did not re-appear unless the voltage was raised to 1500 Volts.

TABLE II

Temperature of Hg Vapours 89° C.

No of glow	Minimum voltage required to initiate the discharge in volts	Voltage on the tube during the discharge in volts	Current of the discharge in M. Amps.	Duration of glow	Interval between successive glows
a (1)	1100 V.	900 V.	3	15 sec.	
(2)	1200 V.	950 V.	4	steady	continuous.

The time lag of discharge was about 3 minutes, the glow continued for 15 seconds, after which the discharge went out. It re-appeared when the voltage was raised to 1200 volts and was continuous for several minutes. The current at the start was 4 milliamperes, but fell to 2 M. Amps. after two minutes and remained constant during the rest of the time.

No. of glow	Minimum voltage required to initiate the discharge in volts	Voltage on the tube during the discharge in volts.	Current of the discharge in M. Amps.	Duration of glow	Interval between successive glows.
b I	1300—1350	was not measured	was not measured	fraction of a second	
II	„	„	„	„	30 sec.
III	„	„	„	„	30 sec.
IV	„	„	„	„	30 sec.

No. of glow	Minimum voltage required to initiate the discharge in volts	Voltage on the tube during the discharge in volts	Current of the discharge in M. Amps.	Duration of glow	Interval between successive glows
I	1400 V.	about 1000 V.	about 1	„	5 sec.
II	„	„	„	„	4 sec.
III	„	„	„	„	5 sec.
IV	1400 V.	about 1000 V.	about 1	fraction of a second	5 sec.
V	„	„	„	„	5 sec.
I	1450—1500 V.	not measured	30—40	„	
II	„	„	„	„	4 sec.
III	„	„	„	„	4 sec.
IV	„	„	„	„	4 sec.
I	1600 V.	not measured	40—50		
II	„	„	„	„	2 sec.
III	„	„	„	„	2 sec.
IV	„	„	„	„	2 sec.

At 1300—1350 volts the time lag of discharge was about 1 minute and the intermittence was regular. When the voltage was increased to 1400 volts, the glows appeared more rapidly. With further increase of voltage the discharge current increased very rapidly; it fluctuated during a glow between 30—40 M. Amps. but since the duration of the glow was very short it could not be accurately measured. The frequency of the glows was also increased. With further increase of voltage the current during the glow was between 40—50 M. Amps. and the glows became still more frequent.

TABLE III

Temperature of Hg Vapours 78°—80° C.

No. of glow	Minimum voltage required to initiate the discharge	Voltage on the tube during the discharge	Current of the discharge in M. Amps	Duration of glow	Interval between successive glows
1	1200 volts	...	...	instantaneous.	
I	1300 volts	was not measured	could not be measured	fraction of a second	
II	„	„	„	„	10 sec.
III	„	„	„	„	10 sec.
I	1350 volts	„	„	„	
II	„	„	„	„	7 sec.
III	„	„	„	„	„

There was an instantaneous flash at 1200 volts and no further discharge was visible, though the voltage was on for more than an hour. The intermittent discharge came in when the voltage was increased to 1300 volts. With the increase of voltage the time between successive glows became shorter.

TABLE IV

Temperature of Hg Vapours 72°C.

No. of glows	Minimum voltage required to initiate the discharge in volts	Voltage on the tube during the discharge in volts	Current of the discharge in M. Amps.	Duration of glow	Interval between successive glows
1	1075 V.	875 V.	4·0	7 minutes	
I	1100 V.	..	10–15	1 second	
II	,,	,,	,,	,,	1 minute
III	,,	,,	,,	,,	1 minute
IV	,,	,,	,,	,,	1 minute
I	1200 V.	...	12–15	about 2 seconds.	
II	,,	,,	,,	,,	1 minute
III	,,	,,	,,	3 seconds	1·5 minute
IV	,,	,,	,,	2 seconds	,,
1	1200 V.	900 V.	4–3·8	continuous	

The discharge appeared when the voltage on the tube was raised to 1075 volts. It was steady and continuous at about 4 M. Amps. and 875 volts. When the voltage was increased to 1100 volts, the discharge became intermittent, with comparatively longer intervals of glow and darkness. The current during the glow fluctuated between 12 and 15 M. Amps. With further increase of voltage the current was slightly increased. The duration of glow and the period between successive glows were also increased. After several minutes the discharge settled down to steady state at 900 volts and 3·8 – 4 M. Amps.

Temperature of Hg Vapours 70°C.

No. of glows	Minimum voltage required to initiate the discharge in volts	Voltage on the tube during the discharge in volts	Current of the discharge in M. Amps.	Duration of glow	Interval between successive glows
I	1075 V.	875 V.	not measured	more than 1 second	
II	,,	,,	,,	,,	10 seconds
III	,,	,,	,,	,,	,,

Intermittent discharge continued for 8 minutes with regular intervals.

Temperature of Hg Vapours 69° C.

No. of glows	Minimum voltage required to initiate the discharge in volts	Voltage on the tube during the discharge in volts	Current of the discharge in M. Amps.	Duration of glow	Interval between successive glows
I	1200 V.	800	4·2	continuous	
II	„	„	3·5—3·4	„	
III	„	„	3·5—3·0	„	

The discharge did not appear till the voltage was raised to 1200 V. The current at the start was 4·2 M. Amps., but gradually fell to 3 M. Amps. after which the discharge went out.

TABLE V

Temperature of Hg Vapours 62° C.

No. of glows	Minimum voltage required to initiate the discharge in volts	Voltage on the tube during the discharge in volts	Current of the discharge in M. Amps.	Duration of glow	Interval between successive glows
I	1400 V	about 1200 V	12–15	2 seconds	10 seconds
II	„	„	„	„	„
III	„	„	„	„	„

Intermittent discharge continued with regular intervals for several minutes.

TABLE VI

Temperature of Hg Vapours 50° C.

No of glows	Minimum voltage required to initiate the discharge in volts	Voltage on the tube during the discharge in volts	Current of the discharge in M. Amps.	Duration of glow	Interval between successive glows
1	1100 V.	850—875 V.	5·0	continuous,	
2	...	900 V.	6·0	„	
3	1400 V	„	7·5	„	
I	1500 V.	...	40—50	fraction of a second	5 seconds
II	„	not measured	„	„	„
III	„	„	„	„	„

Discharge appeared when the voltage applied on the tube was 1100 volts. It was steady at 850—900 V. and 5·0—5·8 M. Amps. When the voltage was

increased to 1500 volts the discharge became intermittent; the current during the glow fluctuated between 40—50 M. Amps.

No discharge passed through the tube when the temperature of Hg vapour was increased above 150° C., by applying a potential as high as 1700 volts.

Discussion

The apparatus was not "baked", nor the electrodes were degassed. The glass walls and the electrodes, therefore. were not free from absorbed gases, which were probably evolved when the discharge tube was heated, in the electric furnace, up to 200°C, during the course of observations which extended over several days.

We cannot make an estimate of the pressure inside the tube, due to the foreign gases, but it seems probable that the discharge is controlled by the total pressure of the foreign gases and Hg vapours, at any temperature. That the Hg. vapours were active in the discharge was apparent from the colour of the glow.

The quantity of gases evolved from the glass walls and the electrodes, and the pressure of Hg vapours vary with the temperature of the tube Moreover, the different sets of observations were taken on different days. The surface conditions of the electrodes, therefore, are not likely to remain the same at all times. They may differ even at the same temperature on different days. Now the sparking potentials and the discharge currents depend mainly on the surface condition of the electrodes; a slight change in their surface condition may bring about a large change in the discharge characteristics. It is, therefore, not justified to compare observations, taken at any time, with those taken at another; nor it is justified to expect a simple relation between the two sets of observations. A few conclusions may, however, be derived from the tables that are typical of a large number of observations taken.

(1) At any one temperature the interval between successive glows becomes shorter with the increase of the tube voltage or discharge current.

(2) If the duration of glow is increased, the interval between successive discharges is also increased.

(3) It appears that the intermittent discharge can take place in Hg vapours over a fairly wide range of pressure.

We express our thanks to the Hon'ble Sir Shah Muhammad Sulaiman and Prof. A. B. A. Haleem for their interest and encouragement throughout this investigation.

References

1. Thomson, J. J., Sir, and Thomson, G. P., ***Conduction of Electricity in Gases***, 3rd Edition, 2nd Volume, page 453.

2. Thomson, J. J., Sir, and Thomson, G. P., ***Conduction of Electricity in Gases***, 3rd Edition 2nd Volume, page 455.

A NEW SERIES OF EXTREMELY SENSITIVE REAGENTS FOR THE DETECTION AND ESTIMATION OF FERROUS IRON IN TRACES

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(Received on November 27, 1939)

SUMMARY

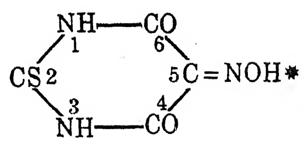
1. Isonitroso-thiobarbituric acid has been found to be an extremely sensitive reagent for ferrous iron, giving dark blue precipitates with moderately dilute solutions and blue colorations with exceedingly dilute solutions of ferrous salts in water.

2. 1 : 3 diaryl-substituted-isonitroso-thiobarbituric acids have also been tried and they have been found to be even better reagents than the parent compound for ferrous iron, yielding comparatively stronger colorations.

3. With the help of these reagents it has been found possible to estimate one part of ferrous iron in about three million parts of water with the help of Helige's three-stage immersion colorimeter. With the same reagents, qualitative detection is possible of one part of ferrous iron in about 5·5 million parts of water.

4. No reagent of such extreme sensitiveness for ferrous iron is known in literature, the nearest approach being made by potassium ferricyanide, capable of detecting one part of ferrous iron in about 75000 parts of water.

Isonitroso-thiobarbituric acid was discovered by Lal and Dutt (1) in 1937, who prepared it by the action of nitrous acid on thiobarbituric acid, and consequently, it had the following constitution :

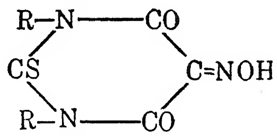


Isonitroso-thiobarbituric acid.

It has often been felt that histories of particular chemical tests were welcome appendices to the discoveries themselves. The iron-reagents-hunt made by Dr. S. B. Dutt has a no less illuminating "historique". In September 1939 one of Dr. Dutt's research students, engaged on preparing iron-gall inks from purely Indian sources, was making use of iron, ferrous sulphate and ferrous ammonium sulphate in combination with tannin extracts in order to find out the ink-base. One day it so happened that, while standardizing the iron salts by the usual methods, he threw a large quantity of ferrous sulphate solution into the sink in order to clean his measuring flask. Almost at the same time, Dr. Dutt wanted to clean a bottle containing a solution of isonitroso-thiobarbituric acid, which was prepared by Lal and Dutt three years ago and used by them for absorption spectra determination. On pouring out the contents of the bottle into the sink, Dr. Dutt found that the entire sink assumed an intense blue colour; and the piecemeal investigations started thence backwards in search of the causes of this amazing colour change led to the discovery of the important iron reagents enumerated in Dr. Dutt's paper. The order of sensibility of these tests is such that further developments in their theoretical and practical applications will be no doubt watched, by chemists and biologists alike, with considerable interest.

—EDITOR.

This compound, which was shown to be a monobasic acid with the hydrogen atom marked by an asterisk being replaceable by basic radicals, was found to yield intense violet salts with alkalis and organic bases, quite a number of which were prepared by the authors during the course of their investigation. From a study of colour and absorption spectra of these salts in relation to their chemical constitution, Lal and Dutt came to the conclusion that their behaviour in these respects lent strong support to the "Theory of colour on the basis of molecular strain" advanced by Dutt (2). In 1938, Dharam Dass and Dutt (1) discovered a new series of aromatic 1 : 3-disubstituted derivatives of isonitroso-thiobarbituric acids with the following general constitution :



1 : 3-disubstituted-isonitroso-thiobarbituric acids. ($R = C_6H_5$; $CH_3C_6H_4$; $(CH_3)_2C_6H_3$; $CH_3OC_6H_4$ and $C_2H_5OC_6H_4$).

These formed green and blue salts with bases, and from the point of view of the theory of colour advanced by Dutt, were equally interesting. But at that time it never occurred to the present author that all these compounds would form exceedingly valuable reagents for ferrous iron, though it was found that they formed coloured compounds with heavy metals just the same as with alkalis and organic bases. Only a little while ago it was discovered, quite by accident, that isonitroso-thiobarbituric acid forms an intense blue precipitate with ferrous salts, the great sensitiveness of the reaction being maintained even at tremendous dilutions of the ferrous compound, while ferric salts did not produce any appreciable change. Further investigations with 1 : 3-substituted derivatives of isonitroso-thiobarbituric acids mentioned above showed that these substances were even more sensitive than the parent compound in this respect, producing dark blue or dark greenish-blue precipitates, opalescences or colorations with ferrous salts at tremendous dilutions. The following substances have been tried as extremely sensitive reagents for ferrous iron, the figures for the relative sensitiveness being given within brackets :

TABLE I

Isonitroso compounds

(1) Isonitroso-thiobarbituric acid (23·6).

(2) Isonitroso-1 : 3-diphenyl-thiobarbituric acid (26).

(3) Isonitroso-1 : 3-di-o-tolyl-thiobarbituric acid (28).

(4) Isonitroso-1 : 3-di-m-tolyl-thiobarbituric acid (31·2).
(5) Isonitroso-1 : 3-di-p-tolyl-thiobarbituric acid (28).
(6) Isonitroso-1 : 3-di-m-xylyl-thiobarbituric acid (29).
(7) Isonitroso-1 : 3-di-o-anisidyl-thiobarbituric acid (35).
(8) Isonitroso-1 : 3-di-p-phenetidyl-thiobarbituric acid (32).

The figures for their relative sensitiveness given above were arrived at by careful comparison with the help of a Helige's three-stage immersion colorimeter, under strictly comparable conditions, the intensity of blue colorations given by their M/100 solutions in alcohol with a N/100,000 solution of chemically pure ferrous-ammonium sulphate dissolved in distilled water saturated with carbon dioxide, the carbonated water being absolutely essential for preventing the rapid oxidation of the ferrous salt to the ferric state by air In the same way, it has been found that with the help of the reagents mentioned above it is possible to estimate one part of ferrous iron *in over three million parts of water*, and that it is possible to detect one part of ferrous iron *in about 5·5 million parts of water*, by the faint blue colorations yielded by these reagents with such dilute ferrous solutions, particularly when the mixtures are viewed from the top of a clear glass cylinder filled to the brim and placed by the side of a similar cylinder filled with only distilled water, for the sake of comparison, on white blotting paper or porcelain slab. No reagents of such tremendous sensitiveness for ferrous iron are known in literature up to this time, the nearest approach being made by potassium ferricyanide, which can detect one part of ferrous iron in about 75000 parts of water.

It is rather interesting to note that none of the reagents mentioned above give any coloration with ferric iron; hence, for the detection and estimation of ferric iron by the present method, the ferric iron must be carefully reduced to the ferrous state, which can be easily accomplished with the help of zinc-copper couple or aluminium-mercury couple and also by palladiumized barium sulphate in presence of hydrogen. Very dilute solutions of ferric salts, on treatment with a solution of ammonium oxalate and exposure to direct sunlight, also undergo quantitative photochemical reduction to the ferrous state, in which they can be directly estimated colorimetrically by the present method. A mixture of ferric and ferrous salts in solution can be estimated by first determining the ferrous component and then the total iron by reduction. The difference between the two results will give the amount of ferric iron present in the original solution.

For the purpose of estimation of ferrous iron in extreme dilution it is essential that the solution should be either neutral or only faintly acidic with a pH value not exceeding 6·5. With more acidic solutions the usual blue colour reactions between ferrous salts and the isonitroso compounds do not take place and the blue colorations or precipitates formed by their interactions are discharged by the addition of an excess of an organic or inorganic acid.

The precipitates obtained by the interaction of ferrous salts with the above-mentioned isonitroso-compounds have been analysed and, from the percentages of iron they contain, they have been found to be true ferrous salts of the isonitroso compounds. When freshly precipitated, they contain varying amounts of water of hydration, but when dried to constant weight at 110°C, they become anhydrous and give correct results of analysis.

Amongst the isonitroso-compounds mentioned above, only the first, that is isonitroso-thiobarbituric acid, is soluble in water, but the others are soluble only in acetone or alcohol-acetone mixture and are precipitated by the addition of water. Hence, in testing for ferrous iron with the help of these latter reagents, it is more convenient to use the ammonium salts of these compounds than the free acids, because the ammonium salts are soluble both in water and alcohol Unfortunately, unlike the free acids, the ammonium salts in solution are not very stable and have a tendency to dissociate into free acids by a process of hydrolysis; consequently, the solutions of the ammonium salts cannot be preserved indefinitely, but can be preserved only for about a week in aqueous solution and about a month in alcoholic solution. The ammonium salts in the solid state, however, are perfectly stable and can be preserved for any length of time. Both the ammonium salts and the free isonitroso compounds give the identical colour reactions with ferrous salts.

Experimental

Preparation of isonitroso compounds.—The isonitroso compounds used in the present investigation were prepared in accordance with the methods described in literature by the previous workers [cf. Lal and Dutt (3) and Dharam Das and Dutt (1)]. The substances were crystallized a number of times from appropriate solvents until they were obtained in a high degree of purity. The ammonium salts of these compounds were prepared according to the directions of the previous authors. M/100 solutions of the free isonitroso compounds as well as of their ammonium salts were prepared, the former in alcohol-acetone (50 : 50) mixture, and the latter in 90 per cent alcohol, and tested against dilute solutions of ferrous ammonium sulphate in carbonated distilled water. The reactions are given in tabular forms at the end of the paper (Table III).

Preparation of pure ferrous ammonium sulphate.—Hundred grams of pure ferrous ammonium sulphate (B. D. H. Analar) were dissolved in 500 c. c. of distilled water previously saturated with carbon dioxide; the solution was rapidly filtered, and the salt, precipitated with pure alcohol, also saturated with carbon dioxide. The precipitated salt was filtered off, washed with alcohol and ether, and dried in a vacuum desiccator. On analysis, the substance was found to contain 14·35 per cent of iron corresponding to the molecular formula $FeSO_4$, $(NH_4)_2SO_4$, $6H_2O$. The

substance was perfectly colourless in appearance. The following solutions of the substance were prepared in distilled water saturated with carbondioxide:

TABLE II

Solutions of ferrous ammonium sulphate in carbonated water.

1. 0·07 gm. per litre (=1 gm. of iron in 100,000 parts of water).
2. 0·007 gm. per litre (=1 gm. of iron in 1,000,000 parts of water).
3. 0·0035 gm. per litre (=1 gm. of iron in 2,000,000 parts of water.)
4. 0·0023 gm per litre (=1 gm. of iron in 3,000,000 parts of water.)
5. 0·00175 gm. per litre (=1 gm. of iron in 4,000,000 parts of water).
6. 0·00140 gm. per litre (=1 gm. of iron in 5,000,000 parts of water).
7. 0·00116 gm. per litre (=1 gm. of iron in 6,000,000 parts of water).

Table III shows the reactions of the various isonitroso compounds given in Table I and also of their ammonium salts in M/100 solution with dilute solutions of ferrous ammonium sulphate given in Table II.

Estimation of iron in the blue precipitates.—A one per cent solution of ferrous ammonium sulphate in distilled water saturated with carbondioxide was treated with a 1 per cent solution of the isonitroso compounds, described in Table I, in alcohol-acetone mixture until the dark-blue precipitate was no longer formed. The precipitate was filtered off, washed with distilled water (carbonated), alcohol and acetone, and then dried first in the vacuum dessicator and then in the air oven at 110°C Table IV gives the descriptions and analyses of these ferrous precipitates.

The analysis of these precipitates was done by taking weighed samples in porcelain crucibles and incinerating them at bright red-heat over a large burner. The final product was thus converted into ferric oxide and weighed as such.

TABLE III

Reactions of isonitroso compounds with very dilute ferrous salt solutions.

Isonitroso compound (Table I) 1cc. of M/100 solution	Solutions of ferrous salts (Table II, 10 cc. of each taken) No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7
No. 1	Deep blue precipitate	Medium blue coloration	Light blue coloration	Faint blue coloration	Very faint blue coloration (Detectable in 100 mm. layers)	Very faint blue coloration (Detectable in 350 mm. layers)	No blue coloration
No. 2	,,	Fine blue precipitate	Light greenish-blue coloration	Faint greenish blue coloration	,,	,,	,,
No. 3	Deep greenish-blue precipitate	Greenish-blue precipitate	Light greenish-blue opalescence	,,	,,	,,	,,
No. 4	,,	,,	,,	,,	,,	,,	,,
No. 5	,,	,,	,,	,,	,,	,,	,,
No. 6	,,	,,	,,	,,	,,	,,	,,
No. 7	,,	,,	,,	,,	,,	,,	,,
No. 8	,,	,,	,,	,,	,,	,,	,,

TABLE IV

Properties of the ferrous salts of the isonitroso compounds

Salt of the isonitroso comp. (Table I)	Colour in the solid state	Remarks	Colour in very dilute solution	Absorption maxima in V. dilute solution (Å)	Analysis (% Fe. theoretical values in brackets)
No. 1	Dark indigo-blue	Prismatic needles	Blue	6010	14·4 (14·0)
No. 2	Do.	Do.	Do.	6030	7·5 (7·95)
No. 3	Dark navy-blue	Microscopic prisms	Greenish-blue	6050	7·0 (7·36)
No. 4	Do.	Do.	Do.	6080	7·1 (7·36)
No 5	Do.	Do.	Do.	6060	7·2 (7·36)
No. 6	Do.	Do.	Do.	6090	6·4 (6·86)
No. 7	Dark greenish-blue	Cubical crystals	Do.	6120	6·2 (6·79)
No. 8	Do.	Do.	Do.	6090	6·0 (6·36)

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CHEMICAL EXAMINATION OF THE ESSENTIAL OIL OF *HEDYCHIUM SPICATUM* HAM.

By Jagat Narayan Tayal and Sikhibhushan Dutt

(Received on August 4, 1939)

SUMMARY

The essential oil from the rhizomes of *Hedychium spicatum* on examination gave the following constituents:

Ethyl-p-methoxy-cinnamate	...	67·8 %
Ethyl-cinnamate	...	10·2 „
d-Sabinene	...	4·2 „
1 : 4-cineol	...	6·0 „
Sesquiterpenes (probably cadinene)	...	5·5 „
Sesquiterpene alcohols	...	4·7 „
Unidentified	...	1·8 „

Hedychium spicatum Ham. is a small herb belonging to the Natural Order of Zingiberaceae. It is found in a wild state in most places in India where the annual rainfall exceeds 50 inches, and is particularly abundant in Bengal, Assam, Kumaun hills, Nepal, Southern Madras and Mysore. Most of the commercial supply, however, comes from Nepal. The tuberous root is an article of commerce, and in the bazaar it is sold mostly in oval or circular slices that are about half an inch or less in diameter and a quarter of an inch or less in thickness The tubers are white and starchy, and the edges of the slices are covered by a rough reddish-brown bark marked with numerous scars and circular rings, with rootlets attached to it here and there. The rhizomes have a pungent, somewhat bitter and camphoracious taste, and the odour is strong and highly aromatic.

The vernacular names of this interesting drug are "Ekangi" in Bengali and "Kapur Kachuri" in Hindi. The tubers are used as a source of perfume, particularly for scenting the "Abir" or the coloured powder which is used during Holi festivals. It is also used as an ingredient in the incense that is burnt before deities in temples, shrines and mosques. In Bengal the rhizomes, after frying and mixing with other ingredients, are used as "Chars" or perfumed baits for fish in ponds, canals and rivers. According to Powell, the rhizomes are pounded with tobacco and smoked in "Hookas" in the Punjab. From the information gathered by the present authors from manufacturers of perfumed tobacco in Benares ("Amburi Tamaku"), it appears that the rhizomes find an important place in the manufacture

of this interesting commodity, which, unfortunately, is gradually falling into disfavour on account of the rapid spread of cigarettes among the rank and file of the population in India.

According to Kirtikar and Basu (1) the aromatic root-stocks are used as a stomachic, carminative and stimulant in Indian Medicine.

The first complete analysis of rhizomes obtained from Indian sources was made by Thresh (4), who showed that the rhizomes contained about 2·5 per cent of an essential oil and many other secondary ingredients. He did not, however, investigate into the nature of the constituents of the essential oil. In 1924 Nakao and Shibuye (2), while working on the Japanese variety of *Hedychium spicatum*, isolated about 2·5 per cent of essential oil from the root-stocks of the plant, about 30 per cent of which was found to consist of ethyl ester of methyl-p-coumaric acid. Pentadecane and traces of cineole were also found to be present. But the essential oil derived from the Indian variety of *Hedychium spicatum* does not appear to have ever been chemically examined by anyone. The present authors, therefore, thought it advisable to subject it to a systematic chemical examination. In the present investigation, the results of this analysis are given.

The essential oil of the rhizomes is obtained fairly easily from the pulverized drug by steam distillation. The yield is nearly 4 per cent of the weight of the dry material. The essential oil, which has a strong characteristic odour of the drug, on allowing to stand for some time, deposits large quantities of a colourless crystalline substance which has been identified to be the ethyl ester of p-methoxy-cinnamic acid. As a matter of fact, it has been found that as much as 67 per cent of the essential oil consists of this substance. The essential oil completely solidifies on cooling in the refrigerator, but on allowing to come to the ordinary temperature, a small portion of it liquefies again. From this behaviour, the presence of ethyl cinnamate was suspected and, on further examination, it was found that about 10 per cent of this substance was also present in the essential oil. Among other ingredients present, d-sabinene and 1 : 4-cineol have been definitely identified, while the presence of cadinene and sesquiterpene alcohols has been tentatively shown. Judging from its composition, the essential oil of *Hedychium spicatum* would indeed form an excellent natural source of p-methoxy-cinnamic acid. In this respect it appears to be much more valuable than the essential oil of *Kaempheria galanga*, which was found to be a satisfactory source of p-methoxy-cinnamic acid by Panicker, Rao and Simonsen (3), because whereas the galanga oil, according to the above-mentioned authors, contains only about 19 per cent. of p-methoxy-cinnamic ester, the Hedychium oil, studied by the present authors, contains more than $3\frac{1}{2}$ times this amount. The intense aromatic odour and spicy taste of the rhizomes are mainly due to the presence of this ester in the essential oil.

Experimental

Eight kilos of the dried tubers were obtained from the local market, and after being pulverized, were distilled from a large distilling apparatus made of copper and fitted with a copper funnel condenser, tinned throughout. The tail fraction of the distillate deposited a white crystalline substance (A), which was filtered off. From the filtered distillate, the essential oil was recovered by extraction with petroleum ether (B. P. 40—60°C), and on removal of the ether, the oil was obtained as a light brown liquid with an intense aromatic odour. On allowing to stand for about a week, the oil deposited large quantities of the crystalline matter mentioned above, and a further quantity was also obtained from the fraction boiling above 180°C/5 mm., when the filtered oil was submitted to vacuum distillation. All these crystalline substances were combined together and recrystallized from light petroleum, when colourless plates were obtained melting at 49-50°C. The yield was about 160 gms.

Examination of the crystalline matter.—The substance is easily soluble in methyl and ethyl alcohols, acetone, ethyl acetate, benzene, chloroform, ether and hot petroleum ether. It gives no colour reactions with alcoholic ferric chloride or potassium hydroxide, and shows no reactions of a carboxyl group. It readily decolorizes bromine in acetic acid and dissolves in concentrated nitric acid with a yellow colour that changes to pink-red on warming. It is insoluble in hot or cold hydrochloric acid. (Found: C=69·39; 69·68; H=6·94; 6·84; $C_{12}H_{14}O_3$ requires C=69·9; H=6·76%. MW=224, 219 by ebulliscopic method in ethyl alcohol; theoretical M.W.=206).

On hydrolysis with alcoholic caustic potash, the free acid was obtained which crystallized from alcohol in glistening colourless needles melting at 172°C. The melting point of the substance was not depressed when mixed with a genuine specimen of p-methoxy-cinnamic acid prepared from anisaldehyde. (Found: C=43·01; 43·12; H=3·42; 3·50: $C_{10}H_{10}O_3$ requires C=43·16; H=3·89%. Molecular weight of the acid by Ag salt=277; theoretical M. W.=278.)

The original crystalline compound is thus identified to be the ethyl ester of p-methoxy-cinnamic acid, which, according to literature, melts at 49 5°C.

Further examination of the essential oil. Isolation of cinnamic acid.—The essential oil, on being kept inside a Frigidaire, completely solidified, but on allowing to come to the ordinary temperature, partially liquefied again. This aroused the suspicion that the oil might contain some ethyl cinnamate, which has a low melting point. A portion of the oil was, therefore, distilled under ordinary pressure, and the fraction boiling between 270—275°C was collected. The saponification value of this fraction was found to be 172. On complete hydrolysis with alcoholic potash and isolation of the acid in the usual manner, a white substance was obtained which crystallized from boiling water in colourless glistening flakes melting at 133°C,

and which was definitely identified to be cinnamic acid by the mixed melting point method (using a genuine specimen of cinnamic acid).

The percentages of ethyl cinnamate and ethyl p-methoxy-cinnamate in the original essential oil were then determined by hydrolysing the esters present and titrating the mixture of acids obtained. The oil it was found to contain 67·8 per cent of ethyl p-methoxy-cinnamate and 10·2 per cent of ethyl cinnamate, it being assumed that no other acids were present.

The constants of the original oil (that is, the oil from which the crystalline matter had not been removed) are given in the following table :

TABLE I

Constants of the essential oil of Hedychium spicatum

Specific gravity at 30°C	0·8824.
Refractive index at 30°C	1·4784.
Saponification value	180·4.
Saponification value after acetylation	195·4.

The constants of the oil from which the crystalline matter had been removed by filtration are given in the following table :

TABLE II

Specific gravity at 30°C	0·8910.
Refractive index at 30°C	1·4810.
Saponification value	115·4.
Saponification value after acetylation ..	125·9.

For the investigation of neutral oil, the crude oil from which the crystalline ester had been removed by filtration was heated with alcoholic caustic potash under reflux on the water bath for two hours. After removal of alcohol by distillation, the terpenes were recovered by passing steam and extracting the condensate with petroleum ether, when a pale yellow oil was obtained. This was then distilled under reduced pressure (70 mm.), when the following fractions were obtained :

TABLE III

Fraction of the neutral oil.

Fraction No.	Boiling range (70 mm.)	Sp. Gr. (30°C)	Ref. Index (30°C)	Saponification value	Yield c.c.	Yield (%)
1	up to 90°C	...	...	...	trace	...
2	90—95°C	0·8429	1·4644	...	12	4
3	95—100°C	0·8501	1·4667	...	6	2
4	100—106°C	0·8576	1·4688	...	7·5	2·5

Fraction No.	Boiling range (70 mm.)	Sp. Gr. (30°C)	Ref. Index (30°C)	Saponification value	Yield c.c.	Yield (%)
5	106—118°C	0·8758	1·4698	...	4·5	1·5
6	118—130°C	...	...	trace	...	...
7	130—150°C	...	...	trace	...	...
8	150—170°C	0·9486	1·4908	15	5	...
9	170—190°C	0·9562	1·5013	9	3	...
10	190—210°C	0·9982	1·5098	4·5	1·5	...

Fraction Nos. 2—6 which were free from aldehydes and ketones were repeatedly distilled under diminished pressure and the results of fractionations are summarized below:

TABLE IV

Refraction of lower boiling fractions.

Fraction No.	Boiling range (100 mm.)	Sp. Gr. 30°C	Refractive index (30°C)	Yield (c.c.)	Yield (%)
11	94—96°C	0·8377	1·4603	4·5	1·5
12	96—98°C	0·8388	1·4631	4·2	1·2
13	98—101°C	0·8391	1·4655	3·3	1·1
14	101—106°C	0·8425	1·4694	6·9	2·3
15	106—108°C	0·8492	1·4702	4·8	1·6
16	108—113°C	0·8529	1·4706	2·1	0·7
17	113—120°C	0·8605	1·4706	3·0	1·0
18	120—125°C	0·8892	1·4680	1·2	0·4

Fractions 11—13 consisted essentially of d-sabinene, the constants of fraction 12 agreeing well with those of this hydrocarbon. The hydrocarbon was oxidised to d-sabinic acid which, after crystallization from hot water, had a melting point of 55—57°C, and a dextro-rotation of 110·7° in alcoholic solution at 30 C. The dihydrochloride after crystallization from dilute alcohol had a melting point of 52°C. The presence of sabinene was thus confirmed.

Fractions 14—18 had a marked camphoraceous odour, which was more intense in the higher boiling fractions. On oxidation with potassium permanganate it was converted into an acid crystallizing from boiling water in colourless needles melting at 157°C, and apparently identical with cinolic acid. The fractions were, therefore, identified to be 1 : 4-cineol.

Fractions 8-9 were repeatedly redistilled and the residue boiling above 150°C/30 mm. was added to fraction No. 10. From the fractions boiling below 150°C/25 mm. a dihydrochloride melting at 116-117°C was obtained. This seemed to be the dihydrochloride of l-cadinene. But this could not be confirmed for want of a genuine sample.

Fraction No. 10 and portions of fractions 8 and 9 boiling above 150°C/30 mm. were distilled together and two main fractions were obtained. The constants of these are given in the following table:

TABLE V

Fraction No.	Boiling range (30 mm.)	Sp. Gr. (30°C)	Ref. index (30°C)
19	155—160°C	0·9817	1·5018
20	160—180°C	0·9842	1·5108

Neither of these fractions yielded a crystalline hydrochloride and hence the presence of any particular alcohol is not definite. The alcohols did not react with phthalic anhydride. They appeared to be, from their general properties, sesquiterpene alcohols.

One of the authors (J. N. T.) wishes to express his indebtedness to the Kanta Prasad Research Trust of the Allahabad University for a Scholarship that enabled him to take part in this investigation.

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THE NUTRITION OF SOME SPECIES OF THE GENUS *PYTHIUM* ON SYNTHETIC LIQUID MEDIA

By R. K. Saksena

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(Received on November 23, 1939)

SUMMARY

1. *Pythium arrhenomanes*, *P. deliense*, *P. graminicolum* and *P. mamillatum* have been found capable of utilizing nitrogen from ammonium nitrate, alanine, asparagine, asparatic acid, glutamic acid, glycine, glycocoll, leucine, bacto-peptone, urea, and, to a less extent, from cysteine hydrochloride and acetamide.

2. Of the fifteen carbohydrates and five alcohols tested as source of carbon for these fungi, dextrose, levulose, maltose, sucrose, starch, dextrin, and glycerine are utilized and are most favourable for growth and acidification; mannose and glycogen are utilized by some of them, while lactose and raffinose are least favourable for the supply of carbon. Arabinose, galactose, rhamnose, xylose, inulin, erythrite, dulcite, mannite, and sorbite are not utilized.

3. Of the nitrogenous substances tested as source of carbon, the organisms utilize alanine, asparagine, asparatic acid, glutamic acid, leucine, and, to a less extent, glycine and glycocoll The carbon from acetamide and urea is not assimilated.

4. Sodium and ammonium salts of acetic, formic, oxalic, tartaric, and citric acids are not sources of carbon for these fungi.

5. The organisms are capable of utilizing sulphur not only from cystine but also from a sulphate, *i.e.*, K_2SO_4.

6. In these experiments, *P. indigoferae* fails to grow in all culture solutions that lack in peptone. It can assimilate dextrose, levulose, mannose, maltose, sucrose, starch, dextrin, glycogen, glycerine, and, to a less extent, lactose, in the presence of peptone.

7. *P. indigoferae* is capable of growing on ordinary agar but not on Difco bacto-agar, which seems to be lacking in some accessory growth factor essential to the fungus. The other four fungi can grow on bacto-agar.

8. All the five organisms are capable of hydrolysing peptone. Ammonification accompanies this reaction.

Introduction

The investigation described in this paper arose in connection with the use of certain synthetic liquid media containing no peptone for intra-vital staining of the vacuolar system of some fungi. It was thought that the fungi listed below would grow in a medium (which will afterwards be referred to as medium M) consisting of 0·1 gm. each of K_2HPO_4, $MgCl_2 \cdot 6H_2O$ and K_2SO_4, 0·8 gm. of NH_4NO_3, 1·0 gm. of pure dextrose (dextrosol of Corn Products Co., New York, U. S. A.) and 1000 cc. of distilled water, but the experiments showed that *Pythium indigoferae*

Butler could not grow in it. This led to the investigation of the nutritional requirements of the fungi. The work is of qualitative nature.

Experiments in this connection were limited by the difficulty and cost of obtaining sufficient quantities of the various substances used, especially of certain amino acids and carbohydrates.

Material and Methods

The species used in these experiments were :—

Pythium arrhenomanes Drechsler,
P. deliense Meurs,
P. graminicolum Subramaniam,
P. mamillatum Meurs, and
P. indigoferae Butler.

P. graminicolum was obtained from Dr. B. L Chona, Ph.D. (London), Sugarcane Mycologist, New Delhi, and the others from the Centraalbureau voor Schimmelcultures, Baarn (Holland). The height of the nutrient solutions (usually 10 cc.) in tubes (16 × 1·5 cm.) was about 5·5 cm. The range of temperature during the experiments was 25—30°C.

All the experiments were run in triplicates. They were repeated once, and twice where results were erratic. In general, the average of at least six readings is given in the tables showing the results of experiments.

In each case the inoculum (4 millimeters in diameter) was taken from the margin of a young colony. Each of the organisms used in these experiments was transferred at least thrice to the same medium before an inoculum was cut off. Care was taken to carry the least amount of the medium along with the inoculum and, therefore, media for this purpose were poured in thin layers in Petri dishes. The medium for the source of inoculum in the case of *P. indigoferae* was agar. In each case the inoculum was allowed to sink down in the nutrient solution.

To ascertain whether a substance tested was really utilized, transfers of each of the fungi were made from a particular medium to the same medium in another set of tubes, and if growth occurred even in the third period of their growth, the tested substance was considered assimilable.

In controls, sources of nitrogen, carbon, and sulphur, were omitted turn by turn. Cultures and transfers were examined macroscopically usually on the eighth day. The hydrogen-ion concentrations of the nutrient solutions were adjusted (unless otherwise stated) to pH 7. before autoclaving. For this work, the colorimetric method of Clark, using Hellige Comparator, was adopted. For the adjustment of pH values, N/5 or N/10 NaOH solution was used. To media that were very acidic, solid sodium hydroxide was added ; its requisite quantity was calculated after determining

the amount of N/5 NaOH solution required to neutralize 10 cc. of a medium. This was done to avoid the dilution of the nutrient media.

The question of the purity of commercial samples is also a matter of importance in such tests. Whenever available, guaranteed reagents (either from Merck or from the British Drug House) were used. Since nutritive substances in low concentrations gave uniformly good results, higher concentrations were not tried. This has also been the experience of Volkonsky (14—16)

In the tables given in this paper, the following signs and abbreviations have been used to denote the type of growth of the colonies and the names of fungi:

O=no growth; R=residual growth due to the nutrient substances being carried along with the inoculum, the hyphæ rise to a maximum height of 0 5 cm.; I=poor growth, the hyphæ rise to a maximum height of 1·5 cm.; II=mediocre growth, the hyphæ rise to a maximum height of 2·5 cm.; III=good growth, the hyphæ nearly touch the surface of the medium; IV=excellent growth, the hyphæ reach the surface of the medium and usually form there a mat of mycelium. Ar.= *Pythium arrhenomanes*; Del.=*P. deliense*; Gr.=*P. graminicolum*; Ind.=*P. indigoferae*; Mam.=*P. mamillatum*.

Nitrogen Metabolism

Basal medium, M_1 = medium M $-NH_4NO_3$.

Medium for the source of inoculum = medium M_1 + Difco bacto-agar.

Magnesium chloride was prepared by the action of pure hydrochloric acid on the clean magnesium ribbon; the commercial, guaranteed reagent ($Mgcl_2 \cdot 6H_2O$) was found to be of no use in these experiments, because it contained traces of ammonia. To the basal medium various nitrogen-containing substances were added singly in 0·1 per cent concentration. The utilization of nitrogen was indicated by the growth of fungi in the media. The results summarized in Table I show that ammonium nitrate, alanine, asparagine, asparatic acid, glutamic acid, glycine, glycocoll, leucine, Difco bacto-peptone, and urea are good sources of nitrogen for the fungi except for *P. indigoferae*. Cysteine hydrochloride is a mediocre, and acetamide a very poor, source of nitrogen. Volkonsky (14) has also reported that nitrogen from acetamide is not assimilated by *Saprolegnia dioica*. On the other hand, a large number of fungi (4, 5, 8, 11 and 14) have been reported to be capable of utilizing nitrogen from organic sources such as amino acids, peptone and urea. and from inorganic ammonium salts.

In the control, which was lacking in a source of nitrogen, there was no growth.

Fungi, like other living organisms, require proteins to build up their bodies, and proteins result from the combination of a number of amino acids. Since *P. arrhenomanes*, *P. deliense*, *P. graminicolum* and *P. mamillatum* can grow in a synthetic medium containing ammonium nitrate, or one favourable amino acid, or

urea, as the only source of nitrogen, it is concluded that these organisms manufacture their own amino acids from ammonium nitrate or from a single favourable amino acid or from urea. These results are in accord with those reported by Leonian and Lilly (8), but are in contradiction with those reported by some other workers who find that a given test organism requires more than one amino acid for its best growth.

TABLE I

Relative growth of the fungi in the basal medium M_1 to which various nitrogenous substances were added singly in 0·1 per cent concentration as source of nitrogen.

Fungi.	Basal medium M_1 (control).	Acetamide.	Ammonium nitrate.	Alanine	Asparagine.	Asparatic acid.	Cysteine hydro-chloride.	Glutamic acid.	Glycine.	Glycocoll.	Leucine	Difco bacto-peptone.	Urea.
Ar.	R	I	III	IV	IV	IV	II	IV	IV	IV	IV	IV	IV
Del.	R	I	III	IV	IV	IV	II	IV	III	III	III	IV	IV
Gr.	R	I	III	IV	IV	IV	II	IV	IV	IV	IV	IV	IV
Ind.	O	0	0	0	0	0	0	0	0	0	0	II	0
Mam.	R	I	III	IV	IV	IV	II	IV	IV	III	III	IV	III

It is remarkable in these experiments that *P. indigoferae* grows only where peptone is available as source of nitrogen. It is possible that the fungus does not grow on account of the low concentrations of the nutrient ingredients of the basal medium or on account of the lack of an accessory growth factor in the medium. It is also likely that it requires a fairly complex nitrogenous substance like peptone as source of nitrogen.

This point will be dealt with in a subsequent communication but it may be here mentioned that the fungus fails to grow even when the basal medium consists of 0·5 gm. each of K_2HPO_4, $Mgcl_2 \cdot 6\,H_2O$ and K_2SO_4, 5·0 gm. of pure dextrose and 1000 cc. of distilled water. The addition of nitrogenous substances in 0·5 per cent concentration did not alter the results. There are indications that even the addition of vitamin B_1 to the basal media will not promote its growth.

CARBON METABOLISM

Basal medium, M_2 = medium M − dextrose.

Medium for the source of inoculum = medium M_2 + Difco bacto-agar.

TABLE II

Relative growth of fungi in the basal medium M_2 to which various carbohydrates and alcohols were added singly in 0·1 per cent concentration as source of carbon; and relative pH values of the nutrient media after the growth of the fungi. (Initial pH of each medium after autoclaving is given at the top).

Fungi.	At the end of VII day.	Basal medium M_2 (control).	CARBOHYDRATES.															ALCOHOLS.				
			Monosaccharides.							Disaccharides.			Tri-saccharides.	Polysaccharides.				Tri-hydric.	Tetra-hydric.	Hexa-hydric.		
			Arabinose.	Dextrose.	Galactose.	Levulose.	Mannose.	Rhamnose.	Xylose.	Lactose.	Maltose.	Sucrose.	Raffinose.	Starch.	Dextrin.	Glycogen	Inulin.	Glycerine.	Erythrite.	Dulcite.	Mannite.	Sorbite.
		6·9	6·7	6·8	6·8	6·7	6·9	6·9	6·7	6·9	6·9	6·9	6·9	6·9	6·9	6·8	6·9	6·9	6·9	6·9	6·9	6·9
Ar.		O	O	III	R	II	R	R	O	O	III	IV	R	II	III	O	O	II	R	O	R	O
	pH=			4·8		5·2					4·8	4·8		4·8	4·9			6·1				
Del.		O	O	III	R	I	III	R	O	R	III	III	O	III	III	II	O	III	R	R	O	O
	pH=			4·5		5·5	4·6				4·4	4·8		4·5	4·6	4·7		4·7				
Gr.		O	O	III	R	II	I	R	O	R	IV	IV	R	IV	IV	II	R	II	R	R	R	R
	pH=			4·7		4·3	6·3				4·5	4·8		4·7	4·9	4·7		6·4				
Mam.		O	O	II	R	II	III	R	O	I	II	II	II	II	I	II	R	II	R	R	O	O
	pH=			4·7		4·9	4·9				4·8	4·9	6·2	4·9	4·7	4·6		6·1				

Various carbon-containing substances were added singly to the basal medium before autoclaving. The utilization of carbon was indicated by the growth of the fungi in the nutrient media. In these experiments *P. indigoferae* was tried only in the second series of experiments.

I Series: (*a*) Of the fifteen carbohydrates and five alcohols tested in 0·1 per cent concentration (Table II), arabinose, galactose, rhamnose, xylose, inulin, erythrite, dulcite, mannite, and sorbite were not assimilated. Dextrose, maltose, sucrose, starch, dextrin, levulose, and glycerine were utilized by the fungi; the first five carbohydrates were most favourable for growth and acidification. Mannose and glycogen were also utilized, the former by *P. deliense* and *P. mamillatum*, the latter by *P. deliense*, *P. mamillatum* and *P. graminicolum*; in each case there was sufficient acidification of the medium. Mannose was poorly assimilated by *P. graminicolum*. Mannose and glycogen were not utilized by *P. arrhenomanes*. Lactose and raffinose were least utilized; these were poorly assimilated by *P. mamillatum* only.

It was found that, in every case, growth was accompanied by the acidification of the medium. This is in accord with the well-established fact that fungi generally produce various organic acids as product of their metabolism in the presence of carbohydrates.

In another set of experiments, the concentration of the carbohydrates and alcohols that were not utilized by the fungi, was increased to 0·5 per cent, but the results were the same. In the control, which was lacking in source of carbon, there was no growth.

(*b*) In order to reduce, as far as possible, the risk of the carbohydrates being hydrolised in the presence of the basal medium during autoclaving, the solution of the carbohydrate to be tested and that of the basal medium were autoclaved separately in tubes and were mixed together after cooling. The tubes were then incubated at 30°C. for three days, but no-one was found contaminated. They were inoculated with fungi. The results were practically the same as already described above.

II Series: In the preceding section it has been stated that *P. indigoferae* grows only when peptone is available. Therefore, experiments were carried out to determine whether the fungus could assimilate carbon from the carbohydrates and glycerine in the presence of Difco bacto-peptone. For a comparative study, the four other fungi were also tried. Dextrose, levulose, mannose, lactose, maltose, sucrose, raffinose, starch, dextrin, glycogen, and glycerine were tested in 0·1 per cent concentration. A medium consisting of 0·1 gm. of bacto-peptone, 2·0 gm. of bacto-agar, and 100 cc. of distilled water, was used for the source of inoculum.

The results summarized in Table III show that after seven days the initial pH of 0·1 per cent solution of peptone was raised from 6·7 to 7·3 by *P. indigoferae*, to 7·5

TABLE III

Relative growth of fungi in 0·1 per cent solution of Difco bacto-peptone to which various carbohydrates and an alcohol were added singly in 0·1 per cent concentration; and relative values of pH of the nutrient media after the growth of the fungi. (Initial pH of each medium after autoclaving is given at the top.)

Fungi.	At the end of VII day.	Difco bacto-peptone (control).	Dextrose.	Levulose.	Mannose.	Lactose.	Maltose.	Sucrose.	Raffinose.	Starch.	Dextrin.	Glycogen.	Glycerine.
		6·7	6·7	6·3	6·7	6·7	6·7	6·7	6·7	6·9	6·7	6·7	6·7
Ar.		III	II	II	I	R	III	II	III	I	III	III	III
	pH=	7·5	5·7	7·3	7·4	6·6	5·4	6·3	7·5	7·3	5·3	7·5	6·9
Del.		III	III	II	III	III	III	III	II	II	II	III	II
	pH=	7·7	6·5	7·3	6·9	7·6	6·3	6·6	7·6	6·3	6·6	6·3	6·7
Gr.		III	IV	III	II	I	IV	IV	III	III	IV	III	IV
	pH=	7·7	5·9	6·3	7·1	7·1	5·7	5·7	7·6	7·3	6·1	7·0	6·9
Ind.		I	I	I	I	I	I	I	I	I	I	I	I
	pH=	7·3	4·1	4·3	4·1	6·5	4·1	4·3	7·3	4·5	4·3	5·3	5·5
Mam.		III	II	II	III	II	II	II	II	II	II	III	III
	pH=	7·5	5·5	5·7	6·3	7·1	5·9	5·9	7·3	5·3	4·9	5·5	7·1

by *P. arrhenomanes* and *P. mamillatum*, and to 7·7 by *P. deliense* and *P. graminicolum* on account of ammonification of the medium during the process of peptone hydrolysis brought about by the growing fungi; qualitative tests made with Nessler's reagent showed the presence of ammonia in the peptone solution.

In another set of experiments the addition of the carbohydrates and glycerine singly to such a peptone solution resulted, in many cases, either in the reduction of the alkalinity or in the acidification of the medium. Wherever such a condition was obtained it indicated the utilization of the substance tested; for organic acids are generally produced with the breaking down of carbohydrates by fungi. Thus, the comparative pH values of the media before and after the experiments threw light on whether a carbohydrate or glycerine was utilized. Most of the results summarized in Table II were confirmed by the experiments described under this series. It was found that dextrose, maltose, sucrose, and dextrin were most favourable for acidification, and that lactose was assimilated, to some extent, in the presence of peptone by *P. graminicolum.*

Generally, the vertical rise of the fungal colonies was less and the colonies were more compact in the peptone solution to which glycine or the carbohydrates were added than in the peptone solution alone.

It is of interest to note that the presence of lactose* (commercial or purified) in the peptone solution inhibits the normal growth of *P. arrhenomanes* in the solution. The addition of lactose to the medium M does not, however, inhibit the normal growth of *P. arrhenomanes* in the medium. It may also be noted here that this fungus is incapable of utilizing glycogen as source of carbon. Drechsler's statement (2) that *P. arrhenomanes* and *P. graminicolum* represent two separate species rather than a single one finds further support in the differential physiological characters of the two organisms (*vide* also 13).

The acidification (Table III) of the media on account of the growth of *P. indigoferae* indicates that the organism can assimilate dextrose, levulose, mannose, maltose, sucrose, starch, dextrin, glycogen, glycerine and, to a less extent, lactose. Although the growth of this fungus was less in comparison with that of others, there was, in its case, much more acidification of the media.

III Series: Of the nitrogenous substances tested (Table IV), alanine, asparagine, asparatic acid, glutamic acid, leucine, and peptone were found to be good sources of carbon especially when they were added in 0·5 per cent concentration, but glycine and glycocoll were mediocre sources of carbon. The carbon contents of acetamide and urea could not be utilized by the fungi.

IV Series: Organic acids, such as acetic, formic, oxalic, tartaric, citric, and succinic acids, were tested as source of carbon. Their sodium and ammonium salts were added singly to the basal medium in 0·1 per cent concentration in one set of

* From Merck (No. 7657, for bacteriological purposes).

TABLE IV

Relative growth of the fungi in the basal medium M_2 to which various nitrogenous substances were added singly as source of carbon.

Fungi.	Acetamide.		Alanine.		Asparagine.		Asparatic acid.		Glutamic acid.		Glycine.		Glycocoll.		Leucine.		Difco bacto-peptone.		Urea.	
	0·1%	0·5%	0·1%	0·5%	0·1%	0·5%	0·1%	0·5%	0·1%	0·5%	0·1%	0·5%	0·1%	0·5%	0·1%	0·5%	0·1%	0·5%	0·1%	0·5%
Ar.	0	0	III	IV	III	IV	II	IV	III	IV	I	II	I	II	I	IV	III	IV	0	0
Del.	0	0	III	IV	III	IV	II	IV	III	IV	I	II	I	III	II	IV	III	IV	0	R
Gr.	0	0	III	IV	III	IV	III	IV	IV	IV	I	II	II	III	I	IV	III	IV	0	0
Mam.	0	0	III	IV	III	IV	II	IV	III	IV	I	II	I	III	I	IV	III	IV	0	0

experiments, and in 0·5 per cent concentration in another. The result showed that carbon from the first five acids was not utilized. *P. arrhenomanes*, *P. deliense* and *P. graminicolum* could utilize carbon to some extent from citric, tartaric, and oxalic acids in the first period of their growth only, but they were not indefinitely transferable in the media where these acids were present as source of carbon. Salts of succinic acids (0·5 per cent) were found to be very good source of carbon for all the four fungi.

The capacity of a fungus to utilize carbohydrates, alcohols, nitrogenous substances and organic acids, etc., as source of carbon depends on their configuration and also on the specific enzymes secreted by the organism. Hence, the results of nutritional requirements of fungi reported by various investigators vary considerably.

Of the carbohydrates, dextrose is the most favourable source of carbon for fungi. Next to it come maltose, sucrose, starch. It has been reported that arabinose, levulose, and xylose are utilized by *Fusarium coeruleum* (10), levulose and mannose by *Spermophthora gossypii* Ashby and Nowell, *Nematospora coryli* Peglion, *N. gossypii* Ashby and Nowell and by an East African strain of *N. gossypii* (5).

Where rhamnose (5), galactose (3, 6 and 7), and lactose (4 and 8) have been reported assimilable, they have been found poor sources

Of the alcohols tested by the author, glycerine is utilized by *Fusarium coeruleum* (10), and mannite by *Phymatotrichum omnivorum* (4).

Volkonsky (14) tested a large number of nitrogenous substances and organic acids as sources of carbon in the case of *Saprolegnia dioica*, and Moore (10) used many organic acids in the case of *Fusarium coeruleum*. Volkonsky reported that alanine, cystine, histidine, and phenylalanine were good sources, asparagine a mediocre, glucosamine a poor and leucine a very poor source. Asparatic acid, valine, glycocoll, and sarcosine were not utilized. Sodium and ammonium salts of acetic, lactic, pyruvic, succinic, tartaric, and citric acids were assimilated.

Moore found that *Fusarium coeruleum* could utilize carbon from sodium salts of tartaric, citric, and acetic acids, and that oxalates and formates were not assimilated as is also the case with the fungi investigated by the author.

Sulphur Metabolism

When the source of sulphur was omitted from the medium M, the fungi failed to grow. The organisms tested could utilize sulphur not only from an organic source, *i.e.*, cystine, but also from a sulphate, *i.e.*, K_2SO_4, and both the sources were found equally good.

There are some fungi such as *Saprolegnia dioica* (14), *S. parasitica*, *Isoachlya monilifera*, *Achlya prolifera*, *A. oblongata*, *A. polyandra*, *A. conspicua*, *Aphanomyces* spp., and *Dichtyuchus monosporus* (15 and 16), which are not capable of assimilating sulphur from sulphates.

Nutritional Effect of Agar

All the five fungi are capable of growing on ordinary agar* on which they are indefinitely transferable. Excepting *P. indigoferae*, the organisms grow on Difco bacto-agar also, though their growth is poor. These results showt hat (*i*) ordinary agar supplies all the ingredients necessary for the growth of the fungi, (*ii*) Difco bacto-agar lacks in some accessory growth factor, which is present in the ordinary agar, and which is essential for the growth of *P. indigoferae*, and (*iii*) this factor is not essential for the remaining four fungi, which can grow on Difco bacto-agar on which they are indefinitely transferable.

Hydrolysis of Peptone

In the case of *Pythium deliense*, *P. de Baryanum* and *P. mamillatum*, the author (12) demonstrated that hydrolysis of 1 per cent solution of Merck's peptone was accompanied by an increse in alkalinity. Recently, Wolf (17) has reported interesting results in the case of *Saprolegnia ferax* and *Achlya bisexualis*. He found that, after inoculation, there was first a lag phase of 6 hours duration, followed by a slight drop in the pH of 2 per cent solution of Difco bacto-peptone, presumably due to the acidity of the mycelium. The initial pH of the solution was 7·1. At the end of 10 hours in the case of *S. ferax*, the pH of the solution became 6·9 approximately and in the case of *A. bisexualis* 6·86 approximately. A gradual rise then occurred and the pH of the solution became 7·8 at the end of 40 hours in both the cases, and subsequently there was no change. With *S. ferax* the rise to maximum pH occurred between 16 and 30 hours, while with *A. bisexualis* between 23 and 40 hours; these observations, however, are not in accord with those reported in the case of *Pythium* spp. by the author (12) who found that a gradual increase in alkalinity continued even up to the end of three weeks. To render the results comparable, Wolf's procedure was adopted by the author in the following experiments.

A fast-growing fungus, *P. deliense*, was inoculated on 50 cc. of two per cent solution of Difco bacto-peptone contained in 150 cc. Erlenmeyer flasks,† and pH determinations and qualitative tests with Nessler's reagent for ammonia were made at 6-hour intervals for 48 hours and then at 24-hour intervals up to the end of the fifth day; at each determination the pH value and the test obtained were compared with those of the control. The medium for the source of inoculum consisted of 0·1 gm. of Difco bacto-peptone, 2·0 gm. of Difco bacto-agar and 100 cc. of distilled water.

The results given in Table V indicate a "lag phase" of 6 hours' duration, followed by a very slight drop in the pH of the solution. Between 12 and 36 hours

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* From Messrs. Townson and Mercer, Ltd., and from Messrs. Turner and Co., Ltd., London.

† One flask for each determination.

the pH of the solution remains 6·85. By this time the fungus colony reaches the surface of the solution. After 36 hours a gradual rise begins, the pH becoming 8·3 at the end of the fifth day.

TABLE V

Progressive pH values of 2 % Difco bacto-peptone during its hydrolysis caused by P. detiense. (Initial pH after autoclaving = 6·9) Temperature 25° C.

At the end of	pH.
6 hours	6·9
12, 18, 24, 30, 36 hours	6·85
42 hours	6·9
48 hours	7·0
72 hours	7·5
96 hours	7·7
120 hours	8·3

A faint yellow colour with Nessler's reagent first appears after 2 hours, thus indicating the presence of ammonia in traces. After 48 hours the reaction becomes more intense, thus definitely indicating the production of ammonia.

In another set of experiments 0·1 per cent of Difco bacto-peptone and all the five organisms were tried. The results summarized in Table VI also show that the increase in alkalinity does not stop at the end of 40 hours, which indicates that ammonification of even the very small amount of peptone (0·05 gm.) is not completed within this period.

TABLE VI

Progressive pH values of 0·1 % Difco bacto-peptone during its hydrolysis caused by the fungi. (Initial pH after autoclaving = 6·9) Temperature 25° C

At the end of	Ar.	Del.	Gr.	Mam.	Ind.
1 day	6·75	6·75	6·75	6·75	6·75
2 days	6·9	6·9	6·9	6·9	6·8
3 days	7·0	7·0	7·0	7·0	6·85
7 days	7·5	7·5	7·5	7·5	7·2

In the case of *P. indigoferae*, which is a slow-growing fungus, a faint yellow colour with Nessler's reagent appears first after 18 hours while in the case of the remaining four fungi it appears after 12 hours.

Conclusions

From the comparative studies of growth of *Pythium arrhenomanes*, *P. deliense*, *P. graminicolum*, *P. mamillatum* and *P. indigoferae*, it is found that the nutritional requirements of the first four fungi are not exacting. It would also seem from the results of this study that the presence of small amounts of minerals and carbohydrates in the soil is adequate for their growth. *P. indigoferae*, which is found in nature as an epiphyte on leaves of *Indigofera arrecta* Hochst (1), seems to be one of those fungi that require a complex of growth-promoting substances for their growth.

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ANNOTATED LIST OF THE HELMINTHS RECORDED FROM DOMESTICATED ANIMALS OF BURMA. PART II—CESTODA

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Introduction

The cestode fauna of Burma has been investigated by Prof. Meggitt and his colleagues, and the present attempt, though principally based on the author's personal observations, is an outcome of Prof. Meggitt's past records. In spite of the relative abundance of the cestode parasites in the domesticated animals, little is known about their pathogenic effects. Cestodes are of special importance to poultry on account of their frequent occurrence and of the severity of the damage caused by them. Sometimes they are obtained so plentifully in a single host that they nearly choke the intestinal passage over several inches and cause mechanical obstruction to the food and interfere with the normal digestion. As far as the author is aware, *Raillietina echinobothrida* is the only form in poultry to which definite symptoms are attributed. It produces in the intestine, usually in the last third of its length, numerous nodules that closely resemble those caused by tuberculosis. Broadly speaking, loss of weight and appetite, droopiness, intestinal catarrh and diarrhœa are the conditions frequently associated with tapeworm infection.

The life-histories of these parasites, so far as they are concerned in the present paper, indicate that the parasites, before infecting the final host, usually pass a part of their life in an intermediate host, necessarily a small one, such as small crustaceans, beetles, weevils, ants, houseflies, grasshoppers, mites, snails, slugs and earth-worms etc. These animals are eaten either accidentally with food or water, or actually as an item of food.

There is no satisfactory anthelminthic for these parasites; this holds good more for poultry than for larger animals such as horse and cattle. Drugs used to cure animals of tapeworm infection have a temporary effect of removing the gravid proglottides without harming the heads; in a few weeks' time these heads produce new proglottides with the same effect as before. The difficulty in removing the heads appears to be purely mechanical. They burrow in the intestinal mucosa or the muscular lining where the effects of the drugs can hardly be felt.

The control for cestode infection lies in prophylactic measures. The faecal matter of the infected animals should, as far as possible, be disposed in such a way that the known intermediate hosts of the parasites are prevented from eating the eggs or segments that are passed along with it.

A growing tendency among helminthologists to lay greater stress on the hosts and host groups is noticed from day to day, and this probably accounts for a large number of synonyms in which Cestoda probably excels other groups of helminths. As examples, well-known forms such as *Dipylidium caninum, Taenia taeniformis,* and *Taenia hydatigena* may be cited where the number of synonyms ranges from 40 to 65. The author believes that the foundation of species on other than morphological characters would render identification impossible. (*Vide* Meggitt 1934, 104.) All the parasites recorded in this paper are obtained from the intestine, unless stated otherwise.

Systematic

Class Cestoda Rudolphi 1808.
Subclass Cestoda (Senu Stricto) Monticelli 1892.
Order Cyclophyllidea Braun 1900.
Family Anoplocephalidae Fuhrmann 1907.
Subfamily Anoplocephalinae Fuhrmann 1907.

Anoplocephala Blanchard 1848.

Key to species*

Testes dorsally in a single layer, cirrus sac 1·5†- 1·8 (elephant). *A. manubriata.*
Testes in 2-3 dorso-ventral layers, cirrus sac 0·5 long (equidae) . . *A. perfoliata.*

Anoplocephala perfoliata (Goeze, 1782).

Host: Horse.

Location: Intestine and caecum.

In slight infections no symptoms are present, but when present in large numbers the parasite causes inflammation of the intestine and sometimes ruptures the wall of the caecum. The attachment of these worms to the wall of the caecum also produces small ulcers at the point of attachment. Life-history is not known, but in all probability it is like that of *Moniezia expansa.* Reported previously by Bhattacharya (1937, 7).

Anoplocephala manubriata Railliet, Henry and Bauche, 1914.

Host: Elephant.

*Numerous works exist in which Keys to genera and families are given: these are therefore omitted here. On the other hand, Keys for the identification of species have, in the opinion of the author, been unsatisfactory and are, therefore, included in this paper.

†All measurements are given in millimetres.

First reported by Meggitt (1926, 230) from Toungoo. Bhalerao (1935, 124) doubts the validity of this species but the arrangement of the testes and the length of the cirrus sac undoubtedly separates this form from the other.

Moniezia Blanchard, 1891.

Key to species

1. Interproglottidal glands absent . . . . . . *M. denticulata.*
   Interproglottidal glands present . . . . 2.
2. Interproglottidal glands arranged in a series of rosettes practically along the whole length of posterior margin of proglottis . . . . . *M. expansa.*
   Interproglottidal glands arranged in a short continuous linear row close to median line of proglottis . . . . *M. benedeni.*

Moniezia expansa (Rudolphi, 1810).

Host: Sheep, goat, cattle and camel.

Usual in goat. Sometimes found exceedingly numerous choking several yards of the intestine. The life-history of this parasite has been recently worked out by Stunkard (1937, 312) and Krull (1939, 10). Stunkard has shown that many free-living mites eat the cestode eggs, the onchospheres hatch in the intestine and migrate to the body cavity of the mite In U.S A. an oribatid mite (*Galumna emarginata*), found in pastures at all seasons of the year, acts as the intermediate host of this parasite. The final host acquires infestation through ingestion of the infected mites. First reported by Meggitt (1926, 230) from the goat and camel.

Moniezia benedeni Moniez, 1879).

Host: Sheep, goat and cattle.

Approximately 4 per cent in goat. First reported by Bhattacharya (1937, 7).

Moniezia denticulata (Rudolphi, 1810).‡

Host: Sheep.

Rare: First reported by Meggitt (1927, 317).

Subfamily Thysanosominae Fuhrmann, 1907.

Stilesia Railliet, 1893.

Key to species.

Vasdeferens with few (3-4) coils . . . . . . *S. globipunctata.*
Vasdeferens with dense coils . . . . *S. vittata.*

Stilesia globipunctata (Rivolta, 1874).‡

Host: Goat.

Recorded by Meggitt (1926, 231).

‡Not found by the author of this paper.

Stilesia vittata Railliet, 1896.

Host: Goat

Occasional: Southwell (1930, 51) holds that this species occurs exclusively in camel. The occurrence of this parasite in goats of Burma fully justifies the remark of Bhalerao (1935, 135) that goat is also a natural host of this parasite.

Avitellina Gough, 1911

Key to species.

Paruterine organ pear-shaped	*A. centripunctata.*
Paruterine organ snail-shaped	*A. lahorea.*

Avitellina centripunctata (Rivolta, 1874).

Host: Goat.

Meggitt's (1926, 231) record of this parasite from goats of Burma has been questioned by some workers. Southwell (1930, 57) without adducing any evidence considers the form obtained by Meggitt as identical with *A. goughi* Woodland 1927. Bhalerao (1936, 141) also has failed to find any trace of this parasite in his plentiful material of Stilesia collected from different parts of India, and has accordingly taken Meggitt's record with some suspicion. The author's finding of this parasite from the goats on a few occasions confirms fully that author's observations.

Avitellina lahorea Woodland, 1927.

Host: Goat.

The author once obtained a portion of a strobilus from the slaughter-house.

Family Davaineidae Fuhrmann, 1907.

Subfamily Davaineinae Braun, 1900.

Davainea Blanchard, 1891.

Davainea proglottina (Davaine, 1860).

Host: Fowl.

Rare: Intermediate hosts are different gastropod molluscs such as *Agriolimax agrestis, Limax cinereus, L. flavus, Arion empiricorum, A. horensis, A. circumscriptus, A. intermedius, Cepaea nemoralis, Arianta arbustorum.* Recently, Levine (1938) has studied the effect of the infection on the weights of growing chickens and has found that when seven-week old chickens were infected with this parasite the average weight of these birds was 2—6 ounces less than the weight of controls from the 35th to 136th day of the experiment.

Raillietina Fuhrmann, 1920.

Key to sub-genera.

Genital pore unilateral, egg-capsules each containing several eggs .	Raillietina.
Genital pore unilateral, egg-capsules each containing one egg . .	Paroniella.

Genital pores irregularly alternate, egg-capsules each containing several eggs . . Fuhrmannetta.

Genital pores irregularly alternate, egg-capsules each containg one egg . . . Skrjabinia.

Subgenus *Raillietina* Stiles and Orlemann, 1926.

Key to species.

1. Eggs 3—5 in each egg-capsule 2
   Eggs 6—13 in each egg-capsule 3
2. Testes 8—10, egg-capsules only just lateral to excretory canal (Pigeon) . . *R. torquata*
   Testes 30—50, egg-capsules distinctly lateral to excretory canal (Fowl) . . *R. pseudoechinobothrida.*
3. Cirrus sac 0·053—0·062 (Duck) . . . . . . *R pseudocyrtus.*
   Cirrus sac 0·075—0·1 (Fowl) . . . . . . *R. tetragona.*
   Cirrus sac 0·13 or more 4
4. Cirrus sac 0·13—0·18, egg-capsules 90—150 (Fowl) *R. echinobothrida*
   Cirrus sac 0·58—0·84, egg-capsules 40—50 (Duck) . . *R. parviuncinata.*

Raillietina (Raillietina) echinobothrida (Megnin, 1881).

Host: Fowl.

Occasional: First reported by Meggitt (1926, 228)

Raillietina (Raillietina) parviuncinata Meggitt, 1924.

Host: Duck.

Occasional: First reported by Meggitt and Po Saw (1924, 3: 4).

Raillietina (Raillietina) pseudocyrtus Meggitt, 1931.‡

Host: Duck.

Meggitt (1931, 253) failed to find any scolex of this parasite and considered it as a dubious species. The characters, as based on the mature and gravid proglottides, show a close correspondence to *R. tetragona*, but pending investigation about the scolex of the former and the absence of any record of the latter from the Anseriformis, the author prefers to consider it separate.

Raillietina (Raillietina) pseudoechinobothrida Meggitt, 1926.

Host: Fowl.

Common: First reported by Meggitt (1926, 230).

Raillietina (Raillietina) tetragona (Molin, 1858).

Host: Fowl.

Usual: Most common of all fowl tapeworms. First reported by Meggitt (1926, 230).

Raillietina (Raillietina) torquata (Meggitt, 1924).

Host: Pigeon.
Occasional: First reported by Meggitt (1924, 307).

Subgenus *Paroniella* Fuhrmann, 1920.

Key to species.

Testes 22—24, cirrus sac reaching nerve (Fowl) . . . . *P. rangonnica.*
Testes 25—40, cirrus sac not reaching nerve (Duck) . . . *P. fecunda.*

Raillietina (Paroniella) rangoonica Subramanian, 1928.

Host: Fowl.
Occasional: First reported by Subramanian (1928. 78).

Raillietina (Paroniella) fecunda Meggitt 1931.‡

Host: Duck.
Rare: Reported by Meggitt (1931, 251).

Subgenus *Fuhrmannetta* Stiles and Orleman, 1926.

Raillietina (Fuhrmannetta) birmanica Meggitt, 1926.

Host: Fowl, duck.
Approximately 17 % in fowl and rare in ducks. First reported by Meggitt (1926, 227).

Subgenus *Skrjabinia* Fuhrmann, 1920.

Raillietina (Skrjabinia) cesticillus (Molin, 1858).

Host: Fowl.
Rare: The intermediate hosts of this parasite are house-flies and various beetles. Ackert and Case (1938, 299) found that when ripe proglottides of this parasite were fed to beetles of the genera *Amara*, *Cratacanthus*, and *Harpalus*, cysticercoids were developed in the body cavities of these beetles in 25—40 days. When mature chickens were fed with these cysticercoids, the adult worms developed in 12—85 days.

Raillietina anatina (Fuhrmann, 1908).‡

Host: Duck
This species cannot be placed in any of the above subgenera owing to lack of anatomical details Reported by Meggitt 1931, 251).

Cotugnia Diamere, 1893.

Key to species.

1. Cirrus sac extending to excretory vessels 2
   Cirrus sac not extending to excretory vessels 4

2. Testes 39—45 . . . . *C. fila.*
Testes approximately 54—75 3
3. Segments longer than broad, musculature weekly developed . *C. cuneata.*
Segments broader than long, musculature strongly developed *C. meggitti.*
4. Length of rostellar hooks 0·008—0·012, testes 5 rows antero-posteriorly . . . . *C. digonopora*
Length of rostellar hooks approximately 0·02, testes 2-3 rows antero-posteriorly . . . . *C. fastigata.*

Cotugnia digonopora (Pasquale, 1890).

Host: Fowl.
Common: First recorded by Meggitt (1926, 226)

Cotugnia cuneata Meggitt, 1924

Host: Pigeon
Frequent: Meggitt (1924, 304) originally described this form as a variety of *C. cuneata* (*C. cuneata* var. *tenuis*), but the other variety (*C. cuneata* var. *nervosa*) having been shown by Yamaguti (1935, 186) as a specifically distinct form, the present name is retained for the former

Cotugnia meggitti Yamaguti, 1935

Host: Pigeon.
This parasite was originally described by Meggitt (1924, 305) as a variety of *C. cuneata* (*C. cuneata* var. *nervosa*) but Yamaguti (1935, 186) considers it specifically distinct

Cotugnia fastigata Meggitt 1920.‡

Host: Duck.
Recorded by Meggitt (1920, 304).

Cotugnia fila Meggitt 1931.†

Host: Duck.
Recorded by Meggitt (1931, 250).

Family Dilepididae Fuhrmann, 1907.

Subfamily Dilepininae Fuhrmann, 1907.

Amoebotaenia Cohn, 1890.

Amoebotaenia sphenoides (Railliet, 1892).

Host: Fowl and duck.
First reported by Meggitt (1926, 232). He records the larval form from *Allolobophora foetida*, *Pheritima peguana* and *Pheritima* sp.

Choanotaenia Railliet, 1896

The uterus of this genus has been the subject of much discussion. Meggitt (1927, 427), Ransom (1909,74), and Southwell (1930, 159) believe that the uterus, though apparently a mass of egg-capsules, is in reality a much sub-divided structure, all the egg-containing cavities communicating with one another, whereas Joyeux (1923, 129), Fuhrmann (1932, 117), and others consider that the uterus is unstable and replaced by true egg-capsules In presence of these diverse statements it is difficult to assign to the present genus its true systematic position, and until further work is done on the subject, the author considers it advisable to place it under the sub-family Dilepininae.

Prochoanotaenia Meggitt, 1924, and *Monopylidium* Fuhrmann, 1899, are considered by Fuhrmann (1932, 117) as synonymous with *Choanotaenia*. As, according to the statements of the various authors, *Monopylidium* has a double row of hooks, and *Choanotaenia* and *Prochoanotaenia* single row, no importance is attached by him to differences in the number of rows of rostellar hooks. (See also definition of *Prochoanotaenia* Meggitt 1924, pp 66) Having stated this view, he yet (l c. 106) holds as valid *Paricterotaenia* Fuhrmann, 1932, a genus which differs from *Anomotaenia* only in the number of hook rows and in the absence of a slightly more anterior extension of the testes—the latter a character of no generic importance. His arguments appear, therefore, to be self-contradictory. The author, having considered the variability in the respective sizes of hooks of the two rows, is of the same opinion as Prof. Meggitt, *i.e.*, the distinction between a single and double rows of hooks is untenable and, therefore, assuming Choanotaenia has a persistent uterus (the type of which allows of a generic distinction), the synonomy is :—

Choanotaenia Railliet 1896.
Anomotaenia Cohn 1900
- *Icterotaenia* Railliet and Henry 1909.
- *Prochoanotaenia* Luhe 1910.
- *Paricterotaenia* Fuhrmann 1932.

Monopylidium Fuhrmann 1899.
- *Macracanthus* Moghe 1925.
- *Megalacanthus* Moghe 1925.
- *Prochoanotaenia* Meggitt 1924.

The genus *Multitesticulata*—considered as a synonym of Choanotaenia by Fuhrmann (l.c. 117)—was created by Meggitt (1927, 317) for the reception of a mole tapeworm, characterized by the vaginal pore being anterior to the opening of the cirrus sac. Baer (1932, 31) showed that this form was of European origin, corrected the observations of the former, and claimed that it, together with *Taenia blanchardi* Mola 1907, was a synonym of *Taenia filamentosa* Goeze, 1782. The

specimens described by Baer and Meggitt show a close correspondence and are undoubtedly the same species; those of Mola differ only in the ventral position of the testes, probably an error of interpretation, and therefore probably also belong to the same species The description and figures of Goeze (1782, 360, Pt. XXVII, fig 6) includes a rostellum, irregularly alternating genital pore and testes practically surrounding female gland Although it is usually inadvisable to identify modern specimens with ancient descriptions on the sole ground of host similarity unsupported by morphological evidence, yet in the present case the correspondence is sufficiently close to justify such a procedure, especially as it results in a clearing-up of the synonyms

That the form should be included in the genus *Monopylidium* as suggested by Baer, or that it should be considered as synonymous with *Choanotaenia* as according to Fuhrmann, is by no means certain. It differs in having the vaginal pore anterior to that of the cirrus sac (shown in the figures of Baer and Meggitt, and indicated by those of Mola). This is the only character which separates *Diplopylidium* Beddard 1913 from *Joyeuxia* Lopez-Neyra 1927, a generic distinction recognized by Fuhrmann (1931, 409), Witenberg (1932, 555) and others. The separation of genera by a single character is recognized in the cases of *Dilepis* and *Lateriporus*, *Diorchis* and *Hymenolepis*, *Distoichometra* and *Nematotaenia*. In view of the relative constancy of the posterior portion of the vaginal pore in the Cyclophyllidea, this character alone is of sufficient importance to justify the separation of two genera. Combined with the dorsal position of the vitelline gland, and the dorsal crossing of the cirrus sac by the vagina the validity of the genus is firmly established. The name of Goeze's species is therefore *Multitesticulata filamentosa*.

Choanotaenia infundibulum (Bloch, 1779).

Host: Fowl

Rare: Southwell (1930, fig. 315) has wrongly inserted the figure of *Metroliasthes lucida* Ransom, 1900, for *Choanotaenia infundibulum*. Intermediate hosts according to Meggitt (1926, 233) are *Geotropes sylvaticus*, and *Musca domestica*.

Subfamily Dipylidiinae Stiles, 1896.

Dipylidium Leuckart, 1863.

Dipylidium caninum (Linnaeus, 1758).

Host: Dog, cat.

Occasional:

Family Hymenolepididae Fuhrmann, 1907.

Subfamily Hymenolepidinae Perrier, 1897.

Hymenolepis Weinland, 1858.

Key to species.

1. Rostellum unarmed, cirrus sac reaching aporal excretory vessel. *H. rustica.*

Rostellum armed 2

2. Rostellum armed with 8 hooks 3
Rostellum armed with 10 hooks 4
Rostellum armed with 18 hooks or more 5

3. Rostellar hooks 0·076—0·082 long, cirrus sac extending nearly to aporal excretory vessel, sacculus accessorius present . . . . . . *H. gracilis.*
Rostellar hooks 0·088—0·095 long, cirrus sac extending beyond aporal excretory vessel, sacculus accessorius absent . . . *H. serrata burmanica.*

4. Sacculus accessorius present . . . . *H. collaris.*
Sacculus accessorius absent . . . . *H. compressa*

5. Sacculus accessorius present . . . . *H. coronula*
Sacculus accessorius absent . . . . . . *H. mehrai* n. sp.

Hymenolepis collaris (Batsch, 1786).

Host: Duck.

Occasional: Previously reported by Sharma (1931) in an unpublished report.

Hymenolepis compressa (Linton, 1892).

Host: Duck.

Frequent: Most common of all the tapeworms of duck. Previously reported by Sharma (1931) in an unpublished report

Hymenolepis coronula (Dujardin, 1845).

Host: Duck.

Rare: Reported by Meggitt (1928, 307). Larval forms recorded from various ostracods such as *Cypris compressa, C. cinerea, C. opthalmica, Cyclops viridis, Caudona rostrata* and *Diaptomus* sp.

Hymenolepis rustica Meggitt, 1926.

Host: Fowl.

Common: First reported by Meggitt (1926, 237)

Hymenolepis serrata birmanica (Meggitt, 1924).‡

Host: Pigeon.

First described by Meggitt (1924, 309) as *H. rugosa birmanica*. *H. rugosa* Clerc, 1906, being a synonym of *H. serrata* Fuhrmann, 1906, the name is automatically changed to its present form.

Hymenolepis mehrai n. sp.

Host: Duck.

Obtained on a few occasions from Rangoon and Kamayut ducks. Maximum length 201 maximum breadth 3·2. Scolex 0·166 long and 0·21 in dia. Rostellum

0·075 × 0·1, with 22—24 hooks, 0·016—0·018 long. Sucker 0·075 dia. Genital pore at centre of proglottis margin. Testes lobed, more or less oval and equal, 0·23—0·332 × 0·21—0·28, shorter antero-posteriorly than transversely. Testes, one on each side of ovary and vitelline gland with the third, though varying in position in a few cases, is usually anterior and internal to the aporal testis, lying in between it and the large external vesicula seminalis. Latter, when fully developed, is pear-shaped, 0·35 long, its posterior end almost reaching ovary and joined anteriorly with the internal vesicula seminalis by a slender coiled duct lying internal to ventral longitudinal excretory duct Cirrus sac 0·42—0·53,

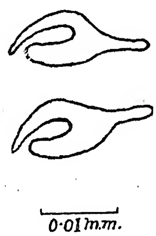

Fig. 1
Hymenolepis mehrai n.sp.
Rostellar hooks

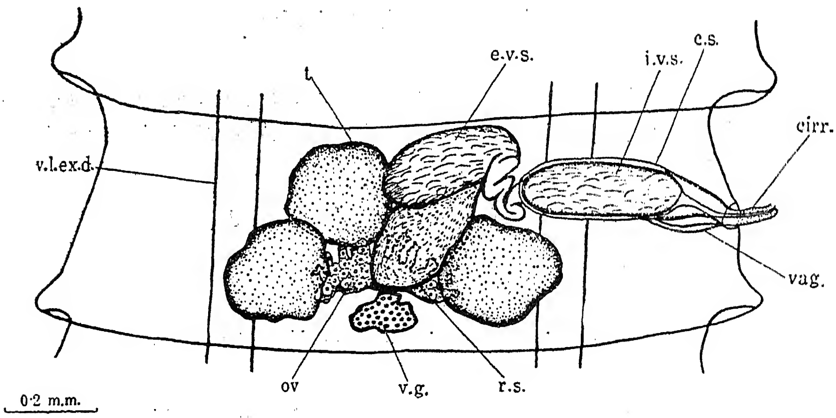

Fig. 2
Hymenolepis mehrai n.sp.
Mature proglottis

Cirr., cirrus; *c.s.*, cirrus sac; *e. v. s.*, external vesicula seminalis; *i. v. s.*, internal vesicula seminalis; *ov.*, ovary; *r.s.*, receptaculum seminis; *t*, testis; *vag.*, vagina; *v.g.*, vitelline gland; *v.l. ex. d.*, ventral longitudinal excretory duct.

extending a little internal to ventral longitudinal excretory duct. Cirrus slender, thin-walled, with minute spines Ovary consisting of a number of well-marked lobes directed anteriorly and laterally. Receptaculum seminis pear-shaped, 0·5 in maximum length, lying bent around median border of poral testis, ventral to vesicula seminalis, extending to ovary or vitelline gland, anteriorly joined to the vagina by a few coils, passing over ventral longitudinal excretory vessel. Uterus very much branched, branches extending external to ventral longitudinal excretory ducts. Eggs, when fresh, 0·08 × 0·03, with two long polar filaments, each 0·68 long.

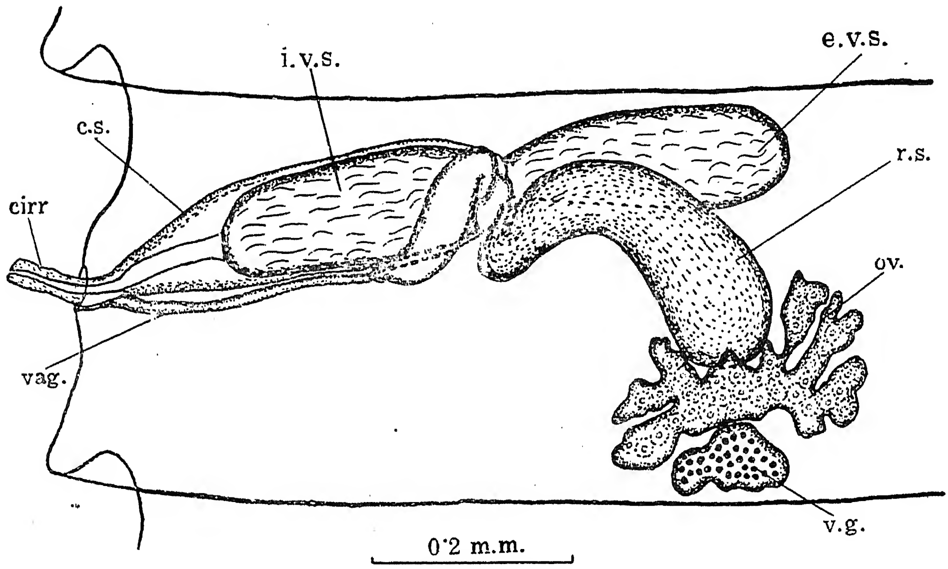

Fig. 3

Hymenolepis mehrai n.sp.

Ventral view, mainly to show the disposition of *vagina and receptaculum seminis*

(Lettering as in figs. 1 and 2)

Neglecting completely the importance of host specificity in matters of specific distinction of cestodes, the present form resembles *H. introversa* (Mayhew 1925), *H. macrostrobilodes* (Mayhew 1925), *H. coronula* (Dujardin 1845), *H. erinacei* (Gmelin 1790), *H macroscelidarum* Baer, 1925, *H. micrancristrota* (Wedl 1855), *H. sacciperium* Mayhew, 1925, and *H straminea* (Goeze 1782) in the approximate number and size of the rostellar hooks. Out of these the present form agrees closely with the first two in somewhat similar shape of the hooks and the shape and arrangement of the testes, all the other species being separated by a marked difference in the former character and a large majority also by the latter character. The points of difference between the present form on the one hand, and *H. introversa* (Mayhew

1925) and *H. macrostrobilodes* (Mayhew 1925) on the other are the differences in the position of genital pore, the relative and absolute size of the cirrus sac, bigger size and greater extent of the testes and a comparatively large size of the eggs in the former. A new species, *H mehrai*, is therefore created in recognition of the valuable contributions rendered by Dr. H R. Mehra in the field of Helminthology

Hymenolepis gracilis (Zeder 1803).†

Host : Duck.

Rare: Reported Meggitt (1920, 308). Larval forms recorded from various ostracods such as *Cypris compressa*, *C. cinerea*, *C. opthalmica*, *Cyclops viridis*, *Caudona rostrata* and *Diaptomus* sp.

Sub-family Fimbriariinae Wolffhugel, 1900.

Fimbriaria Froelich, 1802.

Fimbriaria fasciolaris (Pallas, 1781).

Host: Duck.

Approximately 15 per cent. of the ducks are infected. Previously reported by Sharma (1931) in an unpublished report. Larval forms are reported from ostracod *Diaptomus vulgaris*.

Family Taeniidae Ludwig, 1886.

Taenia Linnaeus, 1758

Key to species

1.	Rostellar hooks 0·38—0·42 (large) and 0·25—0·27 (small)	*T. Taeniformis.*
	Rostellar hooks 0·12—0·26 (large) and 0·09—0·16 (small) . . .	2
2	Uterine branches 9—26	*T. multiceps.*
	Uterine branches 5—10	*T hydatigena.*

Taenia hydatigena Pallas, 1766.

Host: Dog.

Adults from dog are reported by Meggitt (1927, 202) and larval forms from sheep and goat. The larval stage (*Cysticercus tenuicollis*) occurs normally in peritoneal cavity attached to the mesentries and is obtained not only from sheep and goat but also from cattle. In India it has been recorded from pigs It is also recorded from the dog, cat, rodents, monkeys and man, but the correctness of this record is uncertain (See Meggitt 1924, 160-162). The hexacanth embryos, after hatching in the intestine, pass by means of the blood to the liver, where they burrow small channels, eventually reaching the peritoneal cavity after 3-4 weeks Occasionally

they may pass into the posterior vena cava and be transported to other parts of the body. The adult bladder worm may be found anywhere in the abdominal cavity, lying in a delicate cyst formed by the peritoneum The bladder is filled with water and certain amount of organic material with the scolex invaginated into a long neck. The rostellum is armed with 20—48 hooks, with an average of 34 divisible into two sizes, the larger 0·14—0·252, the smaller 0·098—0·158 (Khanna 1928, 76) The final host becomes infected by ingesting these cysticercus

Taenia multiceps Leske, 1780.

Meggitt (1926, 236) has occasionally found the larval Cysticercoids amongst the floor washings and discarded viscera of pig in the pig slaughter house. Normally Cysticercus cellulose—larvae of *Taenia solium*—occurs in the muscles of pig, and *Coenurus cerebralis*—larvae of *Taenia multiceps* - in the brain of sheep and cattle. Southwell (1930, 16) considers Meggitt's forms to be *Cysticercus cellulose*, probably due to identical nature of the hosts. There is no reason, however, for such conclusions when Meggitt has definitely ascertained the forms, by measurements of the hooks, to be larval stages of *Taenia multiceps*.

The larval form is a vesicle which may reach the size of a golf ball It is filled with a fluid and contains a number of heads (approximately 150), which are peculiar in that they occur in clusters which occupy only a small part of the internal wall of the cyst, the rest of it being clear. The final host acquires the infection by ingesting the bladder worm and all or most of the fully formed heads develop into tapeworms

Taenia taeniformis (Batsch, 1786).

Host: Cat

First reported by Meggitt (1927, 202). Larval form is a bladder worm (*Cysticercus fasciolaris*), occurring in the body cavity, liver etc , of rats and mice. Recently, Joyeux, Senevet, and Gros (1938, 26) report the occurrence of larval forms from the domestic rabbit. Vesicle 2-3 in. long and 4 mm broad. Scolex is not invaginated but connected to the vesicle by a long segmented 'neck' bearing no genital organs. When the cysticercus is ingested by the final host the vesicle is digested off, and the rest remains as the scolex and first portion of the worm.

Order Pseudophyllidea Carus 1863

Family Diphyllobothriidae Luhe 1910.

Subfamily Diphyllobothriinae Luhe 1910

Diphyllobothrium Cobbold, 1858

Key to species

Testes 100 – 110 in each proglottis, ova 0·058 – 0·067 × 0·034 – 0·036 . . . *D. ranarum*.

Testes 260 – 300 in each proglottis, ova 0·053 – 0·059 × 0·036 – 0·04 . *D. reptans*

Diphyllobothrium reptans (Diesing, 1850).

Meggitt obtained adults experimentally from dogs (1924, 196). The writer obtained them from fresh faeces of a street dog Larval form is parasitic in snakes, occurring usually in the connective tissue between the dorsal muscles, especially along the vertebral column, and between the skin and dorsal musculature It has been recorded from various species of amphibia, birds and mammals. Meggitt states that all records of this parasite, other than those from reptiles, should be regarded with suspicion

Iwata (1933, 209—247) doubts the validity of the different species of Diphyllobothrium usually obtained from carnivores and, according to him, all such species are synonymous with *Diphyllobothrium erinacei* He believes that the specific plurality of the worm is a result of the examination of the different stages of the adult worm, as he found in the same strobilus (from before backwards) the corresponding characters of *D. reptans*, *D. okumurai*, *D. mansoni*, *D. ranarum*, *D. mansoni* (again reappearing), *D. decipiens* and *D erinacei*, the characters of one merging into another. *D. reptans* differs principally from *D erinacei* in the number and distribution of testes: in the former the number of testes being 260—300 (according to author's observation and an average of 270 according to Joyeux and Houdemer (1928, 41) arranged in two separate lateral bands slightly converging anteriorly, whereas in the latter the number of testes vary from 150 to 240, and are contiguous along the anterior margin of the segment. Even the gravid proglottides of *D. reptans* collected from the faeces of dog bore a clear evidence of this character, and this observation was quite contrary to that by Iwata, according to whom the most posterior gravid segments are similar to *D. erinacei*. Moreover, Iwata (1933, 229) failed to find the proglottides corresponding to those of *D. ranarum* and *D. reptans* in all his worms and the rarity with which such forms occurred in some of the worms of Iwata is not a decisive evidence for the identical nature of the two forms. Hence, the author considers the present form as a distinct species.

Diphyllobothrium ranarum (Gastaldi, 1854).

Host: Dog

Adults first reported by Meggitt (1927, 151) from dog. Larval form of the same type as that of *D reptans* in the muscles of the frog, *Rana tigrina*.

It is my pleasant duty to express my sincere gratitude to Prof. Meggitt for the valuable help rendered in the preparation of these papers, especially of the present one dealing with the cestode fauna. I am also indebted to Dr. H. R. Mehra of the Allahabad University for his unfailing interest in my work and for his assistance in communicating this series of papers.

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